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INVESTIGATION OF BEARING TECHNOLOGY

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INVESTIGATION OF BEARING TECHNOLOGY

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16. Abstract (Limit: 200 words)

This report records and documents Laboratory and Field Test data that demonstrates the superiority of new universal joints that utilize a unique, innovative technological concept. These "GC U-Joint"s were tested on the Propeller Shafts of the HMMWV in direct comparison with Standard universal joints. They are interchangeable.
The new bearings, named "Geometrically Contoured (GC) Bearings" for their design configurations, are made from powdered metal materials. They eliminate roller needles and balls in bearings.

Since the GC design does not require lubrication maintenance, there is no need for the u-joint cross to contain lubrication reservoirs and distribution channels and their input fitting. Their elimination in the "GC Solid" cross enhances the fatigue resistance of the entire universal joint significantly , as well as markedly reducing their manufacturing costs.

Field tests confirm the GC Solid U-Joint provides significant wear performance improvement over the HMMWV standard needle rollered universal joint.

The innovation is not limited to the universal joint. GC Bearings are interchangeable with standard bearings. They provide improved performance with longer life and do so without lubrication maintenance and at reduced unit costs. GC designed bearings can be used to replace Roller Bearings, Ball Bearings and Sliding (Sleeve) Bearings.

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HMMWV
Tactical Vehicle Fleet
Automobiles
Trucks

Powdered Metal Bearing
Wear
No Lubrication
Driveshafts

Rolling Bearings
Sliding Bearings
Bushings
Thrust Washers

b. Identifiers/Open-Ended Terms

Alternators
Pump Bearings
Generators

Starters
Motor Bearings
Steering Shafts

Transmissions
Engine Bearings

c. COSATI Field/Group

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Contents

FRONT MATTER

TEXT

APPENDICES

LIST OF FIGURES AND TABLES

PREFACE

This Final Report documents the successful conclusion of a series of U.S. Army Small Business Innovative Research (SBIR) programs whose purpose was to demonstrate the feasibility of a new, innovative, unique, wear control concept and to demonstrate its application to bearings for the U.S. Army, in general, and specifically to prove its applicability to bearings used in the HMMWV (High Mobility Multipurpose Wheeled Vehicle) universal joints.

The concept is unique, in that it departs, radically, from traditional design theories and production approaches for rolling and sliding bearings & sleeves. Not surprisingly, skepticism existed in the engineering "bearing" community.

Phase I (DAAEO7-91C-R030) demonstrated the feasibility of the design concept and the potential of the new bearings to eliminate lubrication maintenance and to reduce wear significantly. The new bearings are referred to as GC bearings for their "Geometrically Contoured" design configurations.

For Phase II (DAAEO7-93C-R055), the U.S. Army selected the HMMWV and its propeller u-joint bearings as their application. This was done for two reasons. First, to reduce O&S (Operating & Support) costs and improve RAM-D (Reliability, Availability, Maintenance & Durability), notably vehicle availability effected by the demanding lubrication requirements (3,000 miles or 6 months, whichever came first), and second, successful field operational results would prove conclusively the GC bearing's ability to meet the most stringent of operating requirements.

To avoid implication of self-serving data, PMA relied on a third party laboratories to conduct the laboratory tests and to collect and record all the test data. The U.S. Army itself, conducted a series of Field Tests over a three year period (1995-1997) to verify and quantify field performance.

The uniqueness of the new wear control theory has been recognized by the granting of three U.S. and three international patents. Other patents are pending.

The SBIR program was also one of five recipients of the U.S. Army's 1995 SBIR Phase II Quality Award.

The successful results reported here should contribute significantly to the U.S. ARMY's objective of reducing Operating and Support costs for the HMMWV while enhancing its field performance and availability. The potential benefits of universal joint commercialization, as a consequence of the successful conclusion of this project, may now be realized.

Further, the proven capability and availability of a cost reducing, performance enhancing design procedure for bearings in general, is now manifest.

W.J.M.

A. - Summary

This report records the proof of the ability of a new, unique, innovative bearing wear control design concept to reduce the need for lubrication and replacement frequency of the universal joints used by the HMMWV (High Mobility Multipurpose Wheeled Vehicle) and other Tactical Vehicles.

The new bearings incorporating this concept are referred to as "GC" bearings for their "Geometrically Contoured" design configurations. Four bearings ("cups") are employed in an universal joint, twenty on the HMMWV. A universal joint using these bearings is referred to as a "GC U-Joint".

Various independent laboratory and U.S. Army field tests conducted during the three year evaluation period (1995-1997) proved the GC U-Joint's ability to eliminate the need for lubrication at the normal, HMMWV, universal joint lubrication interval (3000 miles or six months whichever comes first).

All laboratory and field tests conducted were a direct comparison, GC vs Standard, one-on-one test. The GC U-Joints showed superior wear performance in all these laboratory and field tests and required no lubrication.

A universal joint employing GC bearings ("cups"), was designed utilizing a cross without any lub channels nor grease fittings. The material employed in the GC cup also permitted the design of an installation "lead-in". The "lead-in" feature of GC cups permits simpler installation and insures accurate alignment of the universal joints within their yokes. This, final, universal joint is referred to as a "GC Solid U-Joint".

Standard HMMWV, universal joints utilize needle rollers in their bearing cups. The GC bearing cup has eliminated the need for these rollers and the need for any maintenance lubrication thereby permitting the use of a solid universal joint (u-joint), i.e. one without lubrication channels and grease (Zerk) fittings in the universal joint cross. These grease channels and fittings weaken u-joint fatigue resistance.

Operationally, the GC Solid U-Joint therefore provides a significant wear performance improvement plus a major improvement in fatigue resistance.

The field tests with HMMWVs employing the GC Solid U-Joints showed them operationally superior to the standard u-joints with their roller needles. The GC Solid U-Joint is interchangeable with standard u-joints.

Though the testing program results demonstrate that periodic maintenance lubrication has been eliminated, and that GC Solid U-Joint may not need to be replaced before the major scheduled HMMWV overhaul every three years, the actual operational life of the GC Solid U-Joint was not established during these tests due to funding limitations.

This program has established that the GC Solid U-Joint is superior, but, however, not to what degree. A Life Test is required. The standard accelerated life tests employed for qualifying rolling bearings is not applicable to sliding bearings. The GC bearing is a sliding bearing.

A HMMWV, GC Solid U-Joint Life Test is required to establish actual operating life of the GC Solid U-Joint in order to correct HMMWV universal joint maintenance and replacement schedules. It is also required to define logistic and procurement requirements.

The GC bearing concept is not limited to universal joint applications. The program has concurrently demonstrated that GC bearings are interchangeable, in general, with various standard rolling (ball and needle roller) and sliding bearings.

B. - Introduction

B.1 - Subject

This final report for Phase II is in reality a final report for the overall program that began in Phase I.

Phase I provided the feasibility demonstration of an application of a new, unique, design procedure which reduces wear so significantly that it eliminates the need for maintenance lubrication and extends the component's life to such a degree that it may not need replacement. It does so, not by eliminating wear, but by controlling it.

The conceptual idea of this radical, new technology is to control the type (i.e.. size, shape and volume) of wear particles generated by the rubbing friction of mating surfaces, and, to remove the deleterious particles from lying between these rubbing surfaces where they would normally continue to accelerate the generation of wear debris, leading to eventual failure.

The type and volume of wear particles generated is controlled by using carefully selected powdered metal materials. Deleterious particles (debris) are removed by the surface configuration design. The benign particles, those that enhance continuos, beneficial, polishing of the surfaces to insure their mutual conformance, are retained.

The use of powdered metals permit a bearing designer to control the particle size, shape and volume of the wear particles as well as the density (porosity) and material composition of the metals used in the bearing.

Phase I demonstrated the feasibility of the new design concept and theory for bearings in direct one-on-one comparative tests with standard bearings.

Phase II focused first, on demonstrating their practical application to high impact torque universal joint bearings employed in the HMMWV Propeller Shaft Drivelines in a laboratory environment, and second, on developing and field testing an entire, new, universal joint employing these new bearings. Their interchangeability with the standard u-joint they replace was also demonstrated.

B.1.1 - History

Pre SBIR Program

The wear control concept is based on the "Wear Particle Theory" postulated and developed by the Principle Engineer and author of this report. It derives from the recognition that wear debris from powder materials and the wear debris from alloyed materials have different characteristics and behave differently.

Based on the author's observations and analyses of wear and wear induced failures, it was established that the traditional wear equations (Abrasive, Adhesive, Corrosive and Surface Fatigue) failed to correctly define and explain the performance of components made from

powdered materials, notably metals. The wearing process of a component made from powdered metallic material is radically different from the wearing process of alloyed materials.

Traditional bearing wear control design methodology today is based on the use of wrought metals, which is an alloying of various metallic elements, i.e. a blending of them in during their heated liquid states. This alloying process establishes the alloys' surface composition and topology in addition to the structure's mechanical properties. The size and shape of the wear debris generated by the rubbing action of mating surfaces is unpredictable and random and uncontrollable. They are primarily the result of surface adhesion and abrasion (i.e. scoring, galling).

In an attempt to control the generation of wear debris, traditional bearing design utilizes the use of balls and needle shaped rollers to separate the surfaces and substitute a rolling action for the sliding. The wear debris generated, however, remains unpredictable and random. The introduction of additional components (balls, rollers) adds considerably to the bearing's cost.

The use of powdered materials permits predictability of the size and shape of the wear debris. The utilization of geometrically configured surfaces controls the generation of the powdered metal wear particles by their selective removal. The bearings employing this new bearing design concept are referred to as Geometrically Contoured (GC) bearings for their surface design configurations. The structurally modified contacting wear surface reduces wear, operating temperature, component fatigue, and other detrimental results of friction. The balls and rollers normally used by these bearings are unnecessary and therefore entirely eliminated.

The GC design procedure is the result of years of development to integrate powdered materials, geometrically contoured surface configurations, and manufacturing technologies.

A detailed explanation of the underlying wear control theory leading to this GC design procedure is contained in a paper presented to the Society of Automotive Engineers entitled "New Bearing Design Concept--An Innovative, U.S. Army, Design Concept for Tactical Vehicle Bearings and Universal Joints".

The entire paper is included as Appendix A . The segments addressing theory and design procedure are Sections A.1-Abstract, A.2- Introduction and A.3- Technical Background and Theory.

SBIR Program - Phases I and II

In 1991 the U.S. Army undertook A Small Business Innovative Research program with Powdered Materials Application, Inc. (PMA) to demonstrate the feasibility of the innovative wear control concept and its ability to eliminate maintenance lubrication in bearings and satisfy bearing operational requirements.

In 1993 Phase II of the SBIR program was undertaken. The U.S. Army sought to establish the practical utility of the GC concept. It chose to confirm the unit cost savings ensuing from the product's manufacturing process and more importantly, the maintenance, inventory, and logistic cost savings resulting from the elimination of periodic maintenance lubrication and the increase in operating life.

The HMMWV was chosen as the test bed vehicle, since its large fleet would provide the greatest overall U.S. Army cost savings.

In 1995 field tests were conducted on the HMMWV at a number of test ranges to establish the GC U-Joints' ability to perform in various environmental conditions (Idaho, Texas, West Virginia, California & Puerto Rico).

In 1997, in order to optimize the performance benefits of the GC bearing design, a series of field tests were conducted at the National Training Center at Ft. Irwin to confirm design modifications developed in the laboratory. The result was the field performance qualification of the GC Solid U-Joint which replaces all current u-joints used by the HMMWV (two separate part numbers) and is interchangeable with them.

B.2 - Purpose

The purpose of the overall SBIR (Phase I and Phase II) project was to establish that a new, innovative, bearing design concept that promised the elimination of maintenance lubrication, unit and logistic cost savings and superior operational performance was technically feasible and operationally practical. Specifically, it had to prove its operational advantages and cost savings on the HMMWV.

The GC Bearing is based on a technical approach which is the first, significantly new and innovative, technological development in bearing design to emerge in many years. It is also based on developing powdered materials technology. Its feasibility was demonstrated in Phase I.

It is the primary objective of this Phase II report is to establish, through laboratory and field test data and results, that this new GC wear control concept and its design procedures and materials, when applied to the HMMWV universal joint bearings has unquestionably met its operational requirements. The HMMWV's Reliability, Availability, Maintenance and Durability (RAM-D) have been enhanced.

The second objective is to demonstrate considerable overall Procurement cost savings. In addition to the Operating & Support (O&S) field cost savings resulting from the superior performance and elimination of maintenance, cost savings also derive in unit procurement costs and inventory.

B.3 - Scope

The scope of Phase II work was originally limited to demonstrating the practicality of the GC bearing design in a direct comparison of GC and standard universal joints on the HMMWV.

Powdered Materials Applications, Inc. (PMA) designed and fabricated GC bearing cups for the HMMWV universal joints. Four bearing cups were mounted on a universal joint cross forming an universal joint. Standard u-joint crosses were used. The GC cups are interchangeable with the standard roller needle cups .

The successful 1995 field tests led to a scope modification. The HMMWV uses two different standard u-joint designs, one for the front propeller shaft, the second for the rear propeller shaft. The scope modification required that one GC U-Joint cup design replace both standard u-joints needle rollered cups. This led to changing the number of GC bearing cups pockets from 20 to 6.

Successful field tests conducted in early 1997 demonstrated that maintenance lubrication is not required for the GC U-Joint in either its front propeller shaft nor its higher load rear propeller shaft application. This led to a second scope modification.

The second scope modification recognized that, since there is no need for field lubrication on GC u-joints, there is no need to use a cross which contains lubrication channels and input grease fittings which weaken its durability and fatigue resistance. The scope modification required that the standard cross be replaced with a solid cross. The solid cross further enhances the overall fatigue strength of the entire universal joint . A GC pocket change from 6 to 12 was included for optimization.

The August/September 1997 field tests completed the qualification of the Solid GC U-Joint.

B.4 - Report Format

This report is divided into three major sections, the Front Matter, Text and Appendices. The outline of the Contents follows this division.

The **FRONT MATTER** of this report provides the reader information necessary to have a general understanding of the project.

The Cover and Report Documentation pages provide data for cataloging and indexing the report for other files. Included on the Report Documentation page is an Abstract which is a concise statement of the report's purpose, scope, findings and their significance.

The Contents form an excellent outline for illustrating the logical flow of the information in the report. It also serves to locate the subject matter quickly.

The figures are entitled so that they easily correlate to related subject text material and other related figures and graphs.

The **TEXT** is the body of the report. It describes the procedures, recorded results, conclusion and recommendations.

The **Summary** restates the principal results, significant conclusions and recommendations of the report.

The **Introduction** explains the historical background and significance of the project. It indicates the Purpose of the project and its objectives. It illustrates how the successful completion of the Scope of the project and its modifications led progressively to the attainment of the primary purpose of this project, the qualification of a HMMWV GC Solid universal joint reflecting a new bearing design procedure that significantly reduces costs and improves performance of universal joints used by the HMMWV and other U.S. ARMY Tactical vehicles using these same universal joints.

The operational requirements of the HMMWV and resulting GC Solid U-Joint qualification procedures are the contents of the **Methods, Assumptions and Procedures** section.

The **Results and Discussions** section presents and reviews the data collected. The data collected and photographs taken of tested universal joints during the series of field tests demonstrating the satisfaction of operational performance requirements over various terrain's is presented. An explanation of the significance of the laboratory and field tests and related photographic data is provided and the high degree of positive correlation of their data illustrated.

The balance of this section evaluates and discusses in detail these results. They are then analyzed and conclusions recorded in the **Conclusions** paragraph.

Recommendations are made identifying the need for a life test to obtain data in order to modify the existing lubrication manuals and schedules to reflect the elimination of periodic lubrication.

At the conclusion of this life test the GC Solid U-Joints should be procured for use on the HMMWV and other Tactical Vehicles which use this part number. Since the universal joints are interchangeable with those currently used, no modifications are required.

Other current bearings on the HMMWV can be replaced by GC bearings. They are discussed.

The last section, the **APPENDICES**, contains a paper presented jointly by PMA's Principle Engineer and TACOM's Technical Representative to the Society of Automotive Engineers (SAE) annual Truck & Bus Technical Convention in November 1997. Its contents are integrated with the above TEXT.

C. - Methods, Assumptions and Procedures

The feasibility of a new bearing concept and design procedure were demonstrated in Phase I by third parties. Bench testing was employed.

A similar approach of third party involvement for independent evaluation and laboratory testing was used in Phase II. NEAPCO, Inc., a supplier of universal joints to the U.A. Army and automobile manufacturers was subcontracted to conduct the laboratory testing. Laboratory data verification and final product (GC Solid U-Joint) qualification was established in field tests conducted by the U.S. Army.

Further, GC bearings were run in direct comparison with the standard universal joints used by the HMMWV during the field tests in order to compare wear patterns and their operational behavior. The GC and Standard u-joints were positioned on the same propeller shafts thereby being exposed to identical torques, speeds and environments.

In order to meet the objectives of Phase II, a three step procedure was employed.

The first step built on the results of Phase I. Step 1 concentrated on designing a GC U-Joint Bearing Cup to meet the requirements and specifications of the HMMWV propeller shaft universal joint, which requires four cups. Five universal joints are employed by the HMMWV. Field tests were conducted for design verification in 1995.

Step two focused on utilizing the laboratory and field test data collected in Step 1 to finalize the material and optimize the GC configuration of the bearing cups . Laboratory and field tests were conducted in early 1997.

Step three was a modification extending the program's scope to design and field test qualify an entire universal joint utilizing the GC Bearing Cups successfully tested in Step 2. Successful qualification was demonstrated in U.S. Army field tests late in 1997.

C.1 - GC Bearing Cup Development

Step 1 -

The primary objective of Step 1 was to establish that a new, innovative, bearing design concept that promised the elimination of maintenance lubrication in Phase I was practical and would meet stringent U.S. Army operational performance requirements and specifications.

The HMMWV was selected as the test bed, since it would provide the U.S. Army with the greatest cost savings for the Tactical Fleet.

Equipment used by all automobile and truck manufacturers and their u-joint suppliers to simulate universal joint operating parameters in a laboratory and to qualify the universal joints for commercial use was employed. The equipment is referred to as "Four Square Test Equipment".

Operating parameters of the Four Square equipment were set at variables used to qualify universal joints (1560 inch-pounds, a 4° shaft angle, 3,000 rpm). The Four Square equipment was limited to 1,750 rpm by equipment problems.

The GC Bearing Cup configuration design of 20 pockets that was successfully demonstrated in Phase I was used as a reference design.

Five powdered metal materials that were compatible with GC configuration requirements were also successfully demonstrated in Phase I (FN, MS 29, MS 40, WEAR-X, WEAR XX). The high torque operational requirements of the HMMWV propeller shaft universal joints reduced the material selection to two, FN and MS 40.

In order to establish which material was superior in actual operating situations under various environmental and climatic conditions, field tests were run at various test sites (Idaho, Texas, West Virginia, California & Puerto Rico).

The design and fabrication of 20 GC pocket bearing cups with FN and MS 40 material was completed in 1994. Laboratory data from the Four Square simulator was also collected then. The field data acquisition was collected in March 1995 at the sites identified above.

Step #2 -

Step 2 focused on optimizing the GC bearing cup surface configuration and selecting a powdered metal material based on the results of the Step 1 laboratory and field tests.

Based on the data collected from the Four Square simulator and the Field Test sites, the GC bearing cup surface configuration was modified. The 6 GC pocket configuration was chosen for the bearing cups. The field tests demonstrated that the MS material used in the bearing cups was superior in performance in the high random impact torques experienced to the FN.

Having established the multi-environment applicability of the GC u-joint in the March 1995 field tests, the design optimization and field qualification was conducted at a single test site, Fort Irwin, California.

After laboratory simulator design and performance verification, field tests were conducted at Ft. Irwin during April and May 1997.

Step #3 -

The Step 2 tests established that the HMMWV optimally uses two different universal joints; one size for the front propeller shaft and a larger, heavier duty, size for the rear propeller shaft.

During Step 3 a bearing cup was designed to simultaneously fit both standard HMMWV universal joints (front and rear) and be interchangeable with them. Also the scope of the program was modified to replace the standard regreaseable universal joints with a solid GC universal joint which does not require relubrication.

The result of these new requirements and specifications was a 12 GC pocket bearing cup mounted on a solid cross. The 12 pocket design and it's compatibility with a solid cross was confirmed on the Four Square simulator in the laboratory. The resulting universal joint is referred to as the "GC Solid U-Joint".

Field tests qualifying the GC Solid U-Joint were conducted at Ft. Irwin in August and September of 1997 .

C.2 - Solid Universal Joint

The Phase II program's objective was to develop GC bearing cups to replace those used on standard universal joints. As the program progressed and the advantages of the GC bearing cup were proven, attention focused on optimizing the entire u-joint.

Specifically, the elimination of maintenance lubrication and the superior operational performance of the GC bearing cup demonstrated that the universal joint cross, which contains reservoirs and channels needed for continuos lubrication grease distribution during the u-joints' operation, were not required. Zerk fittings for grease insertion were also unnecessary.

It should be noted that the "solid" GC Cross is not a newly developed component for the universal joint Industry. A "solid" universal joint cross is identical to the standard crosses in use today except for their modification to eliminate all lubrication reservoirs, grease distribution channels and grease input fittings. The difference is that the original cross forging is not drilled nor tapped to provide these channels and reservoirs. The resulting "solid" cross is thus considerably strengthened, increasing its fatigue resistance.

PMA undertook the development of a "solid" cross to replace the Industry standard grease channeled universal joint cross. The first solid crosses were used with the GC bearing cups during the April and May 1997 phase of the program (Step 2 above).

The HMMWV normally uses two different size standard u-joints; one for the front propeller shaft and the other for the rear propeller shaft. The U.S. Army decided to modify the scope of the program to replace both Standard universal joints with Solid GC U-Joints that use identical, interchangeable, GC bearing cups . A second, a heavy duty, larger, GC Solid U-Joint was developed for the rear propeller shaft.

All GC Solid universal joints were used on the HMMWV in the qualification field tests conducted at Ft. Irwin in August and September 1997 (Step 3 above).

D. - Results and Discussion

Phase II concludes an SBIR program that began in Phase I by demonstrating the feasibility of a radically innovative concept that adds a new theoretical dimension to traditional wear theory considerations and their resulting bearing design technology.

The performance demonstrated by the new innovation do not contradict existing theory and its resulting current design concepts, but they do introduce new theoretical considerations not previously explored which do alter design procedures when powdered materials are used.

First, traditional design procedure concerns itself with <u>alloyed</u> metal materials. <u>Powdered</u> metal materials behave differently in wear situations. Second, traditional wear control design concerns itself with <u>smooth</u> contacting surfaces. This design approach is not applicable to the <u>contoured</u>, interrupted, surfaces required by the GC innovation.

As a result of this unique innovative technology and Phase II's conclusive demonstration of its practical application by subjecting it to compliance to the HMMWV's rigorous operational and maintenance requirements, the new design technology for bearings, sliding and rolling, has been authenticated.

GC Solid U-Joints for the HMMWV and other Tactical Vehicles using these u-joints, like the Five Ton Truck, are now available.

D.1 -General

D.1.1 - Significance of Phase I

The new GC bearing design concept challenges traditional wear theory explaining the metal friction process that leads to the conclusion that sliding bearings are limited in application when high speed and/or a heavy carrying load and/or high impact torque performance are required of a bearing. This then, leads design engineers to further conclude that of rolling components (balls, rollers) must be used to meet these requirements.

The successful feasibility demonstrations of Phase I proved conclusively that by employing powdered materials, whose mechanical properties, powder characteristics and material composition were carefully selected, combined with properly modified (contoured) contacting surfaces, one can not only eliminate rolling components but exceed the performance provided by them.

A complete, detailed, explanation of the underlying theory is provided in Appendix A in the sections addressing theory and design procedures (Sections A.1-Abstract, A.2- Introduction and A.3- Technical Background and Theory).

A succinct summary of Phase I's results is provided in Appendix C.

D.1.2 - Significance of Phase II Field and Laboratory Tests

Phase I had demonstrated the feasibility of a unique and radical innovation to bearing design. It was based on materials and design configurations that when combined produced performance results that were unexplainable by conventional friction and wear theory.

Phase I data promised superior performance and lower cost to bearings, in general, but did not attempt to define specific applications. Further, Phase I's objective did not include developing a body of data establishing maximum operational parameters, i.e. rpm, loading, torque.

The original objective of Phase II was to apply the innovation demonstrated in Phase I to a U.S. Army Tactical Vehicle that would benefit most from a successful application; in operational performance. readiness and cost savings. The HMMWV (High Mobility Multi-purpose Wheeled Vehicle) was chosen. The bearing cups of the HMMWV's propeller shafts' universal joints were selected because they would subject the new GC design procedure to a bearing's most rigorous operational performance and environmental field conditions faced by U.S. Army vehicles.

As discussed in Section B.3 (Scope), Phase II's objective was changed from developing a replacement for the HMMWV's universal joint <u>bearing cups</u> to the development of an <u>entire universal joint.</u> The redirection was a result of highly successful laboratory tests that were confirmed by field testing.

Section C.1 (GC Bearing Cup Development) and Section C.2 (Solid Universal Joint) outline the evolution of developmental progress that led to the qualification of a Solid GC U-Joint as an interchangeable replacement for the standard universal joints in use by the HMMWV today. It does this chronologically.

<u>The role of the laboratory Four Square Simulator</u> was to subject various GC bearing cup configuration designs to the specifications of the standard HMMWV in order to qualify them. Based on an analysis of the field tested u-joints, design modifications were made that required requalification of the GC u-joint on the Simulator before releasing it for field test confirmation.

<u>The role of the Field Tests</u> was to subject the GC u-joints to various field environmental conditions and establish operational acceptability. During these tests, standard u-joints were run on the same shafts with the GC u-joints, so that their wear performance could be directly compared and analyzed. Photographic wear comparisons are illustrated and discussed in Section D.3.1.

As the Solid GC U-Joint evolved, a field test was conducted at each significant step. Step 1 subjected the original 20 pocket GC design to five different environmental conditions. Step 2 demonstrated the applicability of the <u>GC bearing cup</u> to both front and rear HMMWV u-joints. Step 3 qualified <u>Solid GC U-Joints</u> for both front and rear application.

The successful satisfaction of this objective in Step 3 provides the U.S. Army with an immediately available no maintenance, solid universal joint, while simultaneously demonstrating the new concept's GC design procedure's broad range of applicability.

Section 5.2 - HMMWV Operating Performance- in Appendix A, discusses in detail the tests conducted and their results.

D.2 - Advantages of HMMWV GC Solid U-Joints - Field Test Comparisons

To demonstrate the practical utility of the new GC design procedure and simultaneously qualify a bearing for operational use, the U.S. Army decided to subject it to the requirements of the HMMWV. In order to impose the most rigorous operational requirements of the HMMWV's bearings, the propeller shaft universal joint bearing was selected.

The HMMWV employs five (5) standard universal joints, each comprising of four bearing cups.

Three of the u-joints are mounted on the front propeller shaft which connects the engine power transfer case to the front drive wheels and two are mounted on a rear propeller shaft which connects the engine power transfer case to the rear drive wheels. See Figure 7 of Appendix G.

The HMMWV is a four wheel drive vehicle. However, the rear wheels require higher drive torques and a heavier duty u-joint than the front drive. The front u-joint is a 1310 series and the rear is a 1330 series.

Each standard universal joint is comprised of 6 components; four universal joint cups, a cross upon which they are mounted and a Zerk fitting to resupply the grease reservoir for the lubrication of the bearing cups. The cross has four internal lubrication channels which distribute the lubrication grease to the bearing cups and act as grease reservoirs. Each standard bearing cup contains 32 needle rollers.

The Solid U-Joints proven to be superior replacements for the 1310 and 1330 standard series during the execution of the Phase II field tests are identical dimensionally. They are directly interchangeable with the standard u-joints (i.e. without any preparation nor HMMWV component modification).

The external appearance of the Solid GC U-Joint and a standard universal joint is essentially identical. The sole external difference is that no Zerk fitting is attached to the cross. Since no relubrication is required by the GC Solid U-Joint , the Zerk fitting has been eliminated.

The cross used by the GC Solid U-Joint is solid, i.e. there are no lubrication channels machined into it as there are for the standard cross. The cross is, except for the internal elimination of the Zerk input channel and the four lubrication channels, identical. It is the same forged cross that is used for the standard crosses except all the drilling and machining has been eliminated. Cross costs have thus been significantly reduced and the need for this production equipment also eliminated.

The GC bearing cup is radically different from the standard bearing cup. First, it is made of powdered metallic materials and not alloyed metals. Second, the 32 roller needles have been eliminated. Third, the inner smooth surface of the bearing is contoured by 12 pockets and 12 landings. Fourth, the external diameter has been modified to provide an accurate, faster and self aligning insertion of the universal joint into the yokes of the propeller shaft or transfer case.

D.3 Photographic Comparison of GC Solid U-Joint vs Standard Universal Joint

The photographs used in this report were made by the Media Center-Photo Studio at TACOM. Their equipment and skills permitted the required detail display of the wear phenomenon discussed below.

Insertion

Figure 1 compares the GC bearing cup with the standard bearing cup. The substitution of a geometrically contoured 6 pocket inner surface for the 32 needle rollers is easily seen, as is the GC cup "lead-in". The "lead-in" is the reduced outer diameter section which permits the self aligning insertion of the cup into the yoke.

The bearing cup is "press-fit" into the yoke. This holds the cup securely in the yoke in order for the universal joint to function normally. Insertion cup alignment and cup compression (press-fit) are important. A misaligned entry tips the needles and restricts their rolling action. Excess compression during the pressfitting of the cups into the yoke, locks the needles between the bearing cup inner surface and the trunnion surface, restricting their rolling. This forces the needles to be dragged between the surfaces resulting in a wear defined as "scoring". See Table 1 for definition of wear phenomena.

The phenomenon of misalignment or excess compression can be seen visibly on the outer surface and is referred to as "swaging". Figure 2 compares the bearing cups illustrating the "clean" entry of a GC "lead-in" cup and a standard cup with a misalignment swage at the leading edge. The GC cup "lead-in" eliminates this swaging.

Excess press-fit compression results from tolerance build-up. If the yoke diameter is at the low tolerance limit and the bearing cup at the high tolerance, the insertion of the cup compresses its inner diameter reducing or eliminating the clearance needed for the needles to roll properly in a standard needle roller cup. The GC cup does not have needle rollers and its diametric clearance (distance between the trunnion surface and the inner configured surface of the GC cup) has been designed recognizing the tolerance build-up probability.

Figure 3 illustrates the more frequently occurring insertion problem of compression swaging. Swaging was not observed on any of the 184 GC cups field tested (46 u-joints). It was observed on 86 of the 136 (63%) standard bearing cups tested comparatively in field tests.

The PM manufacturing process includes the pressing of the powders into their final shape ("compaction") before they are "sintered"(welded together by heat). This final product is referred to as "net-net", i.e. no secondary work required. The use of powdered materials permits the fabrication of the lead-in automatically during compaction.

WEAR - Brinelling vs Polishing

Figure 4 compares a GC Solid U-Joint cross with a standard u-joint cross after they were removed from a HMMWV after a 1997 field test. See Table 1 for definition of wear phenomena.

Brinelling is evident on both trunnions of the standard cross on the right. The length of the brinnels (almost the full length of the needle rollers) demonstrates that the trunnion surface penetration was

primarily the result of the high impact forces transmitted through the needles by the propeller drive shaft during off-road operation.

Scoring on the standard, needled bearing cupped, universal joint crosses is also evident. This is caused by dragging the needle rollers between the surfaces. The needle rollers did not roll.

The trunnions of the left (i.e. GC) cross show no surface penetration of the trunnions. Unlike the standard universal joint's rollers whose line contact areas penetrate the trunnion surface to cause brinneling, the larger contact area of the GC cup distributes the impact load, so that no surface breakdown results.

The surfaces of the trunnions of the left (GC) cross are polished from the GC cup surface action. The polishing is caused by the use 3-10 micron size powdered metal particles at the GC cup surface. See Appendix A, Section A.3 for a full explanation of the polishing process.

Figure 5 illustrates the extraordinary polishing action of the GC bearing cup.

During one of the field test installations, one standard, needle roller cup cupped, rear propeller shaft, universal joint was missing. To keep the field test program on schedule, it was decided to apply the GC bearing cups to the used rear propeller shaft u-joint that was removed. The condition of the cross trunnion was brinneled similarly to the condition of the brinneled cross shown in Figure 4. After the field test, the brinelling and scoring indentations on the trunnions of the this cross were removed by the polishing action of the GC bearing cup surface.

The cross on the right in Figure 5 shows the polished trunnions of this previously brinneled/scored cross. This polishing is compared to trunnions(left cross) that were polished by the GC bearing cup that does not use needle rollers.

Heating Fatigue

In the normal course of a standard bearing's operating life (either sliding or rolling) wear debris is generated by the deterioration of the surfaces in contact with each other or with the rolling member (ball or roller). The wear debris is accumulated, since it cannot be removed. The temperature of the bearing increases with debris accumulation. Further, the size of this debris is steadily enlarging, forcing the ball/roller to slide raising the bearings temperature rapidly. If not removed, the bearing will jam and fail and cause severe damage to itself and to other related componentry.

This process is described in detail in Appendix A, Section A.3. Also described and documented is an explanation of how the GC concept and design procedure prevents this wearing process from occurring. Simply stated, (1) the contoured surfaces of a GC bearing cup remove the debris generated by contacting surfaces, and (2) powdered material of selected characteristics control the size of the debris generated. Figures 5 and 6 of Appendix A presents data that illustrates that GC bearings resultingly run cooler than standard bearings.

The excessive heat that is generated preceding a failure tempers the material. The increasing temperature can be seen on the body of the component, progressing from lighter hues (tan, bronze) to higher temperature darker colors e.g.. blue.

Figure 6 compares GC and Standard (needle rollered) bearing cups when they were removed after a field test. The standard cup on the right shows considerable bronze hue heating while the GC cup on the left shows none. This excessive heating of standard cups can also be seen in Figure 1 and

Figure 2. The GC cups in these figures exhibit no such heating. Figure 3 illustrates two (2) standard cups that have blue rings indicative of extreme temperatures.

Figure 7 illustrates a heat ring resulting from overheating of a brinneled standard universal joint trunnion.

Table 1. - Definitions of Wear

For purposes of this report PMA adheres to bearing industry definitions of surface wear:

Polishing = smoothing of a surface ; an improvement in surface finish;
Scuffing = slight surface roughing; surface asperity tips (abrasion) breaking loose and lodging between surfaces and being dragged between them.
Scoring = deep surface roughing; plowing of surface by relatively large asperity material that has broken off (by impact) or torn off (by abrasion) one of the mating surfaces;

Swaging = plowing of a surface by a rougher, harder surface; unlike polishing, scuffing or scoring, which are continuing rotating processes, swaging is an one time insertion phenomenon;

Spalling = stressed surface that introduces sub-surface cracks which evolve into surface pitting and cause portions (area) of surface removal; caused by rolling pressure or sliding adhesion;
Galling = similar to spalling, but caused by heavier rolling or adhesive impact pressures; larger, wider and deeper sections of surface are removed;

Brinelling = deep surface penetration caused by large impact loads; associated with balls or rollers: balls cause holes from point contact, rollers cause lengthy furrows from line contact; a subsurface crack is normally introduced; if balls or rollers are trapped in their crevice or are forcibly dragged out , scoring results.

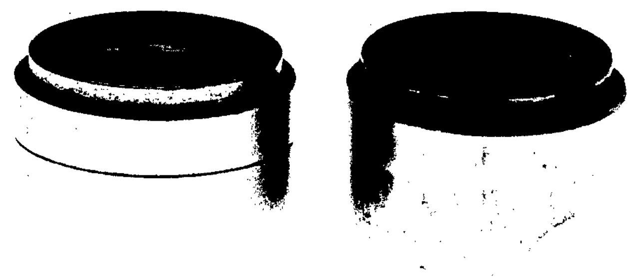

Figure 1 - GC and Standard Bearing Cups

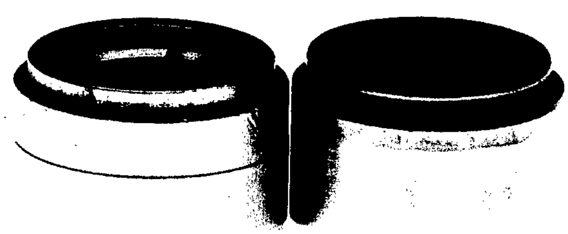

Figure 2 - Entry Alignment Swage on Standard Cup

Figure 3 - Press Fit Swages on Standard Cups

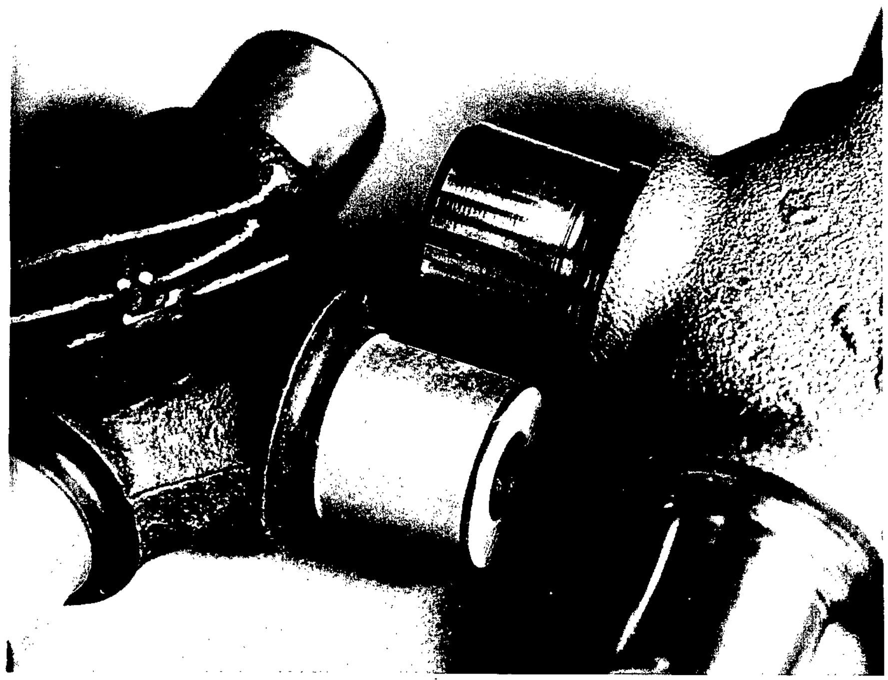

Figure 4 - GC Polishing Action vs Standard Roller Brinelling Action

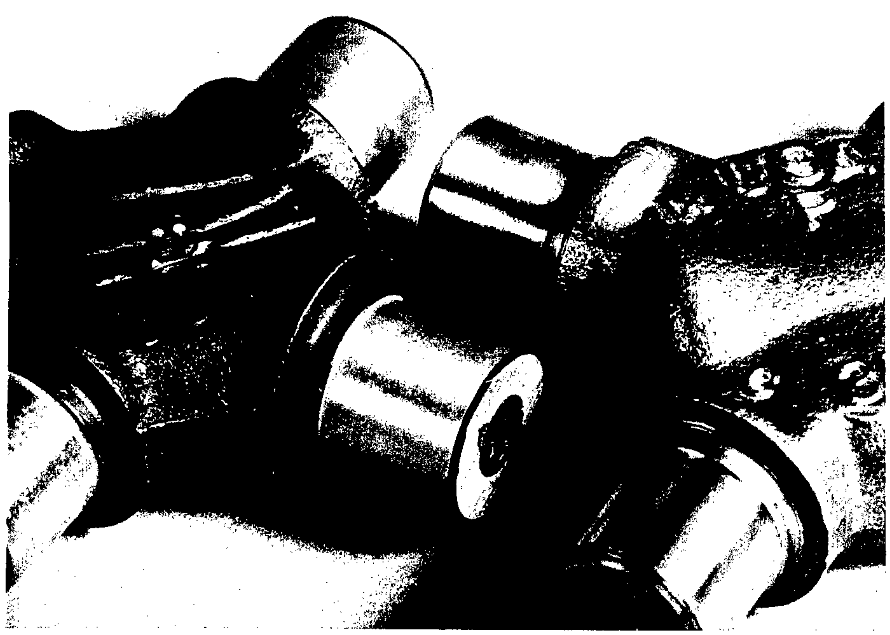

Figure 5 - GC Polishing Removing Standard Roller Brinelling

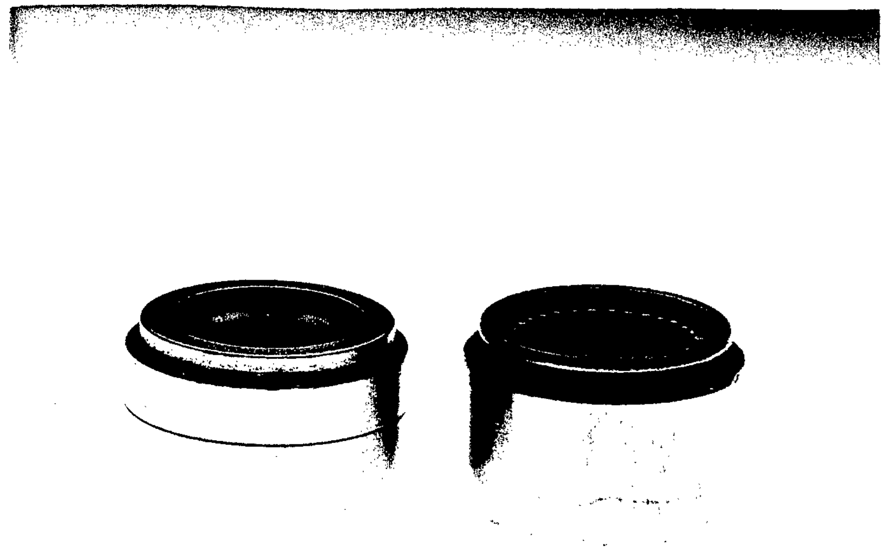

Figure 6 - Cup Heating- GC, None; Standard, Excessive

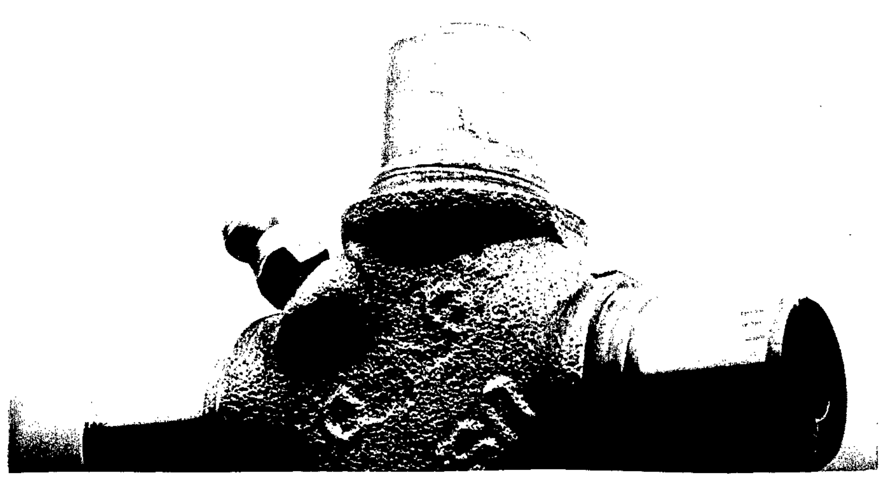

Figure 7 - Cross Trunnion Heating by Standard Cup's Rollers

D.4 - SAE (Society of Engineers) Paper

A technical paper discussing this program was presented at the SAE International Truck & Bus Meeting & Exposition in November 1997. It was entitled "New Bearing Design Concept -- An Innovative, U.S. Army Design Concept for Tactical Vehicle Bearings and Universal Joints".

The paper is included in its entirety in Appendix A. The requirements for publication of the paper necessitated its submittal before all the data and photographs of the last of the final field tests were available. The slides representing this information that were used in the presentation but are not included in the paper are provided in Appendix H.

The data obtained after the paper was written do not effect its conclusions. As stated during the oral presentation, they reinforce them.

The preparation and the presentation of this paper was divided into two major segments. The first segment discusses the technical background and underlying theory of this innovation in considerable technical detail. It also discusses the conduct and data analysis of the concept's general feasibility (Phase I).

It then discusses, specifically, the qualification of the HMMWV GC bearing cups and the GC Solid U-Joint in the laboratory tests conducted on the Four Square equipment during Phase II. This segment was prepared by the Walter J. Maciag, the developer of the GC wear theory and the program's Principal Engineer.

The second segment of the paper discusses each of the four series of field tests in detail. These tests were conducted by the U.S. Army under the direction and personal field involvement of Mr. Mark A. Mushenski, TACOM's (Tank-Automotive and Armaments Command) Program Manager. He prepared and presented the second segment of the paper.

E. - Concluding Remarks

HMMWV and Other Tactical Vehicles:

The GC Solid U-Joints developed for the Front and Rear Propeller Drivelines have demonstrated their performance superiority to the standard universal joints during the field tests conducted by the Army. This was discussed in detail in Section D.3 and illustrated by the photographs of Section D.3.1., The following additional benefits are provided by a GC Solid U-Joint when they replace the standard u-joint used by the HMMWV today.

1- The GC Solid U-Joint is approximately 35-40% less expensive than the standard u-joint in use today. The unit cost saving is derived from (a) the use of a needleless PM bearing cup that is press formed into net, net shape and (b) the use of currently used standard crosses that require no drilling nor machining for the lubrication channels and input grease fitting, since re lubrication has been eliminated and (c) the elimination of components, e.g.. roller needles and Zerk grease input fittings.

2- Installation of the GC Solid U-Joint is simpler and faster due to the lead-in on the external diameter of the cup. As a result of the lead-in, the alignment is truer. The lead-in is automatically formed as part of the net, net PM cup. No special tools nor manufacturing operations are required.

3- The elimination of needles and cooler operation reduces the HMMWV's NVH signature (noise, vibration and heat).

4- The use of a solid cross increases its fatigue resistance and reduces universal joint failure.

5- The elimination of periodic lubrication and longer u-joint operating life, increases the HMMWV field readiness. Logistics and maintenance requirements are reduced.

6- O&S (Operational & Support) costs, e.g.. inventory, maintenance and logistics, are reduced.

7- RAM-D (Reliability, Availability, Maintenance and Durability) field performance is greatly enhanced.

8- GC Solid U-Joints are interchangeable with standard HMMWV universal joints.

9- The GC Bearing Cup has been designed to be interchangeable with standard rolling cups and, therefore, can be mounted on standard crosses. No new crosses are required.

10- Production has been simplified. Equipment for machining and grinding cups, and equipment for drilling lub channels and tapping grease fittings, are not required. Capital investment is reduced. Labor content is reduced.

11- The permanent solid lubricant applied during assembly is not toxic and complies with EPA requirements. The elimination of maintenance service further reduces exposure and increases personal safety.

12- Production of GC Bearing cups, which are press molded in dies, insure greater dimensional repeatability and consistency (SPC - Statistical Process Control) than bearing cups relying on skilled labor machining.

13- All Tactical vehicles employing the same HMMWV part number universal joints can use the GC Solid cross immediately, e.g.. Five Ton Truck.

14- The HMMWV u-joints are equivalent to the commercial u-joints most commonly designated as the 153-X and 213-X. Different manufactures have their own designations that are interchangeable with these numbers. The HMMWV u-joints are interchangeable with these commercial part numbers.

Bearings In General

Bearings fall into two classes of application: (1) transmission of power and (2) supporting rotating equipment.

When power is transmitted from its generating source (e.g.. engine) to the final point of application, at low speeds, gears are normally used. Higher speeds require the use of bearings. Because of the high torque power being transmitted, rollers are used in these bearings (e.g.. universal joint). Ball bearings cannot sustain these loads.

Bearings used to support rotating components (e.g.. shafts) fall into three additional sub-classes: (1) roller bearings, (2) ball bearings and (3) sliding or sleeve bearings.

The roller bearing is used when the load it supports is "heavy", typically in excess of 1000 psi (pounds per square inch) regardless of its rotating velocity (rpm/sfm - revolutions per minute/surface feet per second.

When the supported loads are lighter, either the ball bearing or sliding bearing can be used depending on its rotational speed. When the revolutions exceed approximately 500 sfm, ball bearings must be used.

Phase II has proven that the new bearing wear design technology utilizing selected powdered materials with configured surfaces (GC bearing) can be used for high torque transmission applications formerly limited to the higher cost roller bearing. The Army field tests demonstrated the superior performance of the GC bearing on the HMMWV. (See Section D.3).

Phase I has proven the GC bearing is significantly superior to the sliding/sleeve bearings employed today. In direct one-on-one comparisons with commercial self lubricating, powdered material bearings, the GC bearings continued to operate after the commercial bearings seized and failed. At the point of commercial bearing failure, the temperature of a six pocket GC bearing had reached an equilibrium demonstrating that the extent of its operating life far exceeded the standard commercial counterpart but its actual life was not established.(See Appendix A, Figure 5.)

Though not the scope of either Phase I nor Phase II, PMA developed a GC bearing that can be used interchangeably with a popular industrial ball bearing. It has been applied successfully, however, PMA has not conducted tests to establish its maximum rotating velocity and life.

It is concluded that the GC bearing design concept has demonstrated its applicability in all three bearing application domains. It is clearly superior in all sliding/sleeve applications. In rolling applications, it has shown superiority to both roller and ball bearing situations in limited applications but in all rolling situations offers considerable cost savings.

The potential benefit to U.S. Manufacturing, domestically and internationally, appears to be significant in light of the GC concept's patent protections. This area of study was beyond the scope of the program.

F. - Recommendations

F.1. - Life Test - Establish the Operational Life of the GC Solid Universal Joints

Having qualified the GC Solid U-Joints for use on the HMMWV in its front and rear propeller shafts, the first priority would be to establish the actual operating life of the GC Solid U-Joint.

The GC Solid U-Joint in actual field tests has demonstrated superiority to the standard u-joints currently used by the HMMWV. Analysis of field tested GC Solid U-Joints showed no need for additional lubrication. A number of HMMWVs have logged mileage approximately up to the normal 3,000 mile periodic lubrication maintenance requirement, however, none of the HMMWVs were run beyond it. (The length of the HMMWV's field tests were determined by Ft. Irwin's test schedule.) Though analysis showed no need for lubrication, the HMMWVs were not run beyond this point to establish when a maintenance or replacement would be necessary.

It is recommended that the GC Solid U-Joints be run on a Auto & Truck manufacturer's test track for distances necessary to establish the operating life of the HMMWV GC Solid U-Joints. To accurately simulate usage conditions, the test should be designed to run the vehicle at varying speeds. Also, the vehicle should be run intermittently in order to subject the GC Solid U-Joint to the periodic cold starts it normally experiences. The running intervals should be between one and two hours. Downtime should last approximately 20 minutes.

If participation by an Auto & Truck manufacturer cannot be arranged, it is recommended that the U.S.. Army conduct tests similar to those conducted in Phase II at Ft. Irwin, which are continuously being conducted on the HMMWV. The only difference in the field tests would be to control the operational mileage the HMMWVs log in the field. Based on results to date, it would be appropriate to expose the GC Solid U-Joint to increments of 6,000 miles (double the standard u-joint requirement) without lubrication maintenance, at which time GC Solid U-Joints can be evaluated.

The Four Square Simulator normally used commercially to determine component life does so by modifying parameter set-up variables to accelerate results and to reduce the test period. The Four Square simulator variables of universal joints have been established from data collected from universal joints containing needle rollers in the bearing cups. The Four Square Test parameters have, as a result, been determined from rolling bearing information. A sliding bearing, like the GC Solid U-Joint, requires actual mileage (wheel revolutions) and cannot be accelerated in a Simulator.

As an alternative to a Test Track, the Four Square Simulator could be utilized, however, the test parameters must be set to the HMMWV's maximum operational requirement and not to the accelerated parameters determined for a roller bearing universal joint. As in the test track evaluation, the simulation of the u-joint propeller driveshafts would follow the running/downtime procedure discussed above.

Subsequent to the establishment of the operating life of the GC Solid U-Joints, the universal joints should be purchased for application to all Tactical vehicles employing the HMMWV front (153X) and/or rear (213X) propeller shaft u-joints.

F.2. - Commercial Application of the HMMWV U-Joint

Auto & Truck manufacturers should have an interest in the GC Solid U-Joints because of their cost savings. In addition, the improved operating performance will permit them to extend their warranty coverage. Field and laboratory tests indicate that GC Solid U-Joints can be warranted for the lifetime of the vehicle.

The HMMWV front propeller driveshaft universal joint is the most commonly used u-joint in automotive applications, and the rear propeller driveshaft universal joint is the most commonly used light truck and van u-joint. They are generally designated as the 153X and 213X, respectively.

The unit cost saving of 35-40% of the GC Solid U-Joints should prove desirable.

Contributions to this cost saving accrue from both the cups and the cross. The cup, made from powdered metal, is formed net-net, i.e. no machining. The use of a solid cross eliminates the drilling, machining, tapping and grinding operations normally required. Labor content is reduced.

GC cups can be used to replace the standard needle rollered cups directly, since they are interchangeable. Existing crosses can be used.

Auto & Truck manufacturer subcontracted u-joint suppliers can be directed to substitute the GC cup on the supplier's "solid" cross resulting in reduced prices.

Capital investment is also reduced. Equipment for machining and grinding cups, and equipment for drilling lub channels and reservoirs and tapping Zerk inputs in the crosses is no longer required.

An important U.S. Auto & Truck manufacturer's consideration should be the patent protection provided domestically against off-shore competitors for aftermarket sales. A "lifetime", lower cost, replacement u-joint can be offered to domestic and export markets.

F.3. - Sliding Sleeve Bearing Replacement in Tactical Vehicles

It is recommended all sliding (smooth) bearings be examined for replacement by GC Bearings. In this category of bearing are included bushings, washers, thrust washers and sleeves. Phase I clearly demonstrated the superiority of GC Bearings to sliding bearings directly in one-to-one comparisons.

Specifically, the powdered metal "self lub" bearings used by the HMMWV and other Tactical vehicles can be interchangeably replaced, immediately, without additional qualification testing. It was demonstrated in Phase I that Self Lub bearing performance and life can be improved significantly simply by applying Geometrically Contoured surfaces. The PM material need not be changed.

F.4. - Continue Development of Low Cost, No Maintenance GC Bearings for Other Needle Roller Bearing Replacement

The final recommendation is aimed at applying the GC Bearing concept to all HMMWV Rolling Bearing applications, especially those bearings also used in other U.S. Army applications. It is recommended that a study be conducted identifying bearing part numbers and their procurement history.

Non-HMMWV bearing part numbers with high volume inventories for application in other vehicles (Tactical and Logistic) and Field Equipment (Generators, Motors, Pumps) should also be conducted. With a cost differential in excess of 50% for a GC replacement, considerable cost savings can be expected.

Appendices

SAE TECHNICAL PAPER SERIES

973178

New Bearing Design Concept

An Innovative, U.S. Army, Design Concept for Tactical Vehicle Bearings and Universal Joints

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ABSTRACT

A radically new approach to the design of bearings demonstrated feasibility in a U.S. Army SBIR[1] program. It was first applied to universal joints on the HMMWV (High Mobility Multipurpose Wheeled Vehicle) in order to maximize the concept's performance benefits and optimize vehicle cost savings. The program[2] was one of five recipients of the U.S. Army's 1995 SBIR Phase II Quality Awards. The concept has been issued three patents[3]. This paper presents the theory and documents HMMWV field test results in the successful development of a new universal joint with bearings that eliminate field lubrication and provide a major reduction in maintenance.

INTRODUCTION

It is the purpose of this paper to illustrate the utility of the new, innovative, bearing design procedure to all bearing, rolling and sliding, applications.

This is done by specifically demonstrating the resolution of a HMMWV field maintenance problem. The frequency of universal joint lubrication (4,827 km (3000 miles) or 3 months, whichever comes first) reduces the combat readiness and availability of the vehicle. The new bearing's ability to function without relubrication and ease of installation due to its design features provided the field maintenance improvement needed.

TECHNICAL BACKGROUND AND THEORY

The components employing this new bearing design concept are referred to as Geometrically Contoured (GC) Bearings for their design configuration which structurally modifies the contacting wear surfaces in order to reduce wear, operating temperature and other detrimental results of friction. They are made from powdered materials. The balls and rollers normally used by these bearings are eliminated. See Figure 1.

A powdered metal, sliding, bearing with geometrically contoured (modified) surface outperforms normal roller & ball bearings and also the powdered metal sliding bearings in many current applications.

At the macroscopic level, the GC Bearing removes the destructive wear debris that is generated between the contacting surfaces ceasing further surface deterioration and wear. This is done by the contoured surface which provides pockets for their removal.

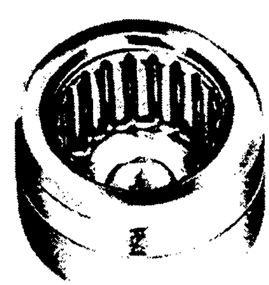

Figure 1. GC Bearing (No Rollers)

At the microscopic level, it prevents the actual generation of these wear particles in the first place. This is done by selecting a PM material with the desired size and shape powders that are compatible with the composition of the lubricant selected. These must promote the proper interaction with the macroscopically determined contour design. Figure 1 shows the design used on the HMMWV universal joint cups compared to those shown in Figure 2, that they replace.

Traditional bearing wear control design methodology today is based on the use of wrought metals, which is an alloying of various metallic elements, i.e., a blending of them in their liquid states. This alloying process establishes the alloys' surface composition and topology in addition to the basic structure's mechanical properties. The size and shape of the wear debris generated by the rubbing action of mating surfaces is unpredictable and random. They are generally a result of a surface adhesion and abrasion (i.e., scoring, galling).

Two techniques are most commonly used for measuring the size of wear debris in lubricating oil samples of various large operating equipment in order to protect this equipment.

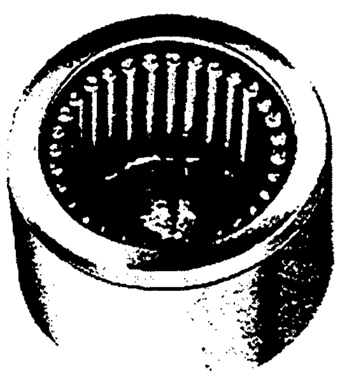

Figure 2. Standard Bearing With Rollers

Research employing Ferrography[4,5] and Atomic Emission Spectrometry[6] has been able to establish a correlation between the operating life of lubricated equipment and the size and shape, and the volume, of the debris found in a sample of its lubricating oil[7]. Figure 3 illustrates typical wear debris size distribution and concentration.

A large concentration, i.e., volume of wear particles, normally signals replacement of lubricating oil, however, it is not the primary threat[8] to bearing life. The presence of randomly shaped debris with approximate diameters of 15 µm or more, regardless of concentration, is truly the most accurate indicator for the need of immediate attention. A large concentration of these particles indicates that the entire bearing must be replaced, not simply the lubricating oil. The >15 µm sizes additionally promote rapidly the generation of still larger, more disastrous sizes of debris.

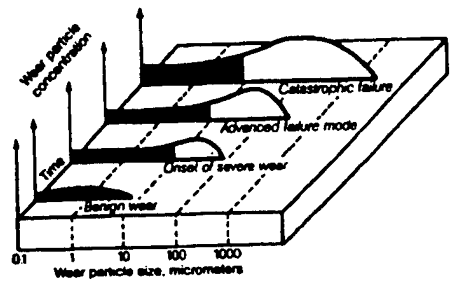

Figure 3. Wear Particle Size Concentration

Debris below 3 µm are not a factor in failure. A large concentration of this size is, in fact, beneficial because it polishes the surfaces rendering the surfaces less susceptible to the generation of larger, failure causing, wear particles. If the volume continues to increase, however, the lubricating oil must be replaced, but, not the entire bearing.

The surface wear behavior process for components made from powdered metal materials (PM) behaves differently. This results directly from the use of powders whose generated debris particles reflect the powders dimensions thus differing greatly from the wrought metal debris. The powdered metal wear debris particles, unlike an alloyed material, are largely predictable.

Most importantly for our bearing design innovation, any impact or rubbing shearing action, creates debris that reflects the size and shape of the original powders. The particle size spectrum of powders available for use extends from 0.1 to 1000 µm[6]. They range from ultra fine (0.1 to 1 micron) to coarse (100 to 1000 micron)[9] as shown in Figure 4. Thus, fine powders in the beneficial size range (<3µm) can be chosen. Further, spherical shapes, the least detrimental shape in a bearing rubbing action, can also be selected.

Those used in the GC bearings are in the fine (1-10 micron) range.

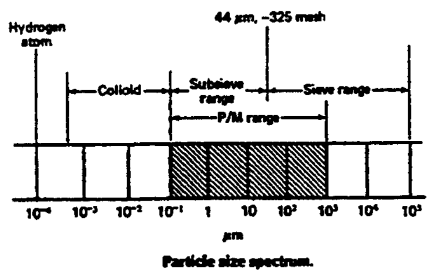

Figure 4. Particle Size Spectrum

Powdered materials are first mixed, which is a non-liquid, non-chemical, blending. The powders are then pressed into the desired component's shape and dimensions (Compaction). Bonding of the powdered elements follows and is done in furnaces (Sintering) at controlled temperatures that do not permit the mixture to reach a liquid state. The elemental bonding process is basically a weld between powders. As the powders bind in sintering, their surfaces also round (smoothen), reducing sharp edges.

The resulting mechanical properties and surface topography, even for alloyed materials with identical compositions, can be significantly different. Since powders do not reach a liquid state, metallurgical and chemical combinations are possible that cannot be combined in the liquid, alloying state.

A universal joint bearing cup, does not operate simply to reduce friction. It is also required to transmit power, i.e., transmit large torque. In the case of the HMMWV universal joints, these heavy torque loads can be as much as 4 to 5 times a normal automotive load of 445 to 668 N (100 to 150 ft-lb.). Additionally, unlike rotating bearings, universal joints oscillate producing large impacts on the surfaces.

In order to limit the amount of wear debris generated by the combination of impact and rubbing actions, and to remove the wear particle debris caught between the rubbing surfaces, a number of surface designs were examined before selecting the design appropriate to the HMMWV requirements.

SBIR PHASE I: FEASIBILITY DEMONSTRATION

To meet the primary objectives of the Phase I portion of the SBIR project, which were to demonstrate the feasibility of the GC concept and the new bearing design theory, bench tests were conducted at an independent laboratory[10]. The tests were a direct one-to-one comparison between standard sleeve bearings and these same bearings whose contacting surfaces were modified by a GC surface design. The GC Bearing was compared to a PM Self Lube Bearing. The reason for this was to eliminate all ancillary variables that may be misconstrued as to having an effect on the GC bearing's performance. The GC Bearing had the identical powdered material and impregnating oil as the Self Lube Bearing. It was made from the same dies except for the punch that created the pockets for the GC configuration. This eliminated any doubt that any improvement in performance was not a direct result of the GC configuration in a powdered material component, the only difference between the bearings.

Both bearings were simultaneously run on the same shaft, and were subject to identical loads, speeds and ambient environment. The tests were automatically terminated by a failure of one of the bearings. Failure was defined as an average bearing temperature in excess of 177^{o} C (350^{o} F) which normally precedes a bearing seizure. A thermocouple sensor was located on the body (external surface) of the bearings to trip a shut down mechanism in the event of overheating. The data was continuously recorded on a strip chart recorder.

At the time of the failure of the standard PM sleeve bearings, the feasibility and superiority of their GC counterparts were conclusively demonstrated by two GC designs that continued to run at significantly cooler temperatures as shown in Figure 5.

One design (3-GC, i.e., three debris collecting pockets) was 18^{o} C (65^{o} F) cooler at the time of the standard sleeve bearing failure; the second design (6-GC) was 51.7^{o} C (125^{o} F) cooler.

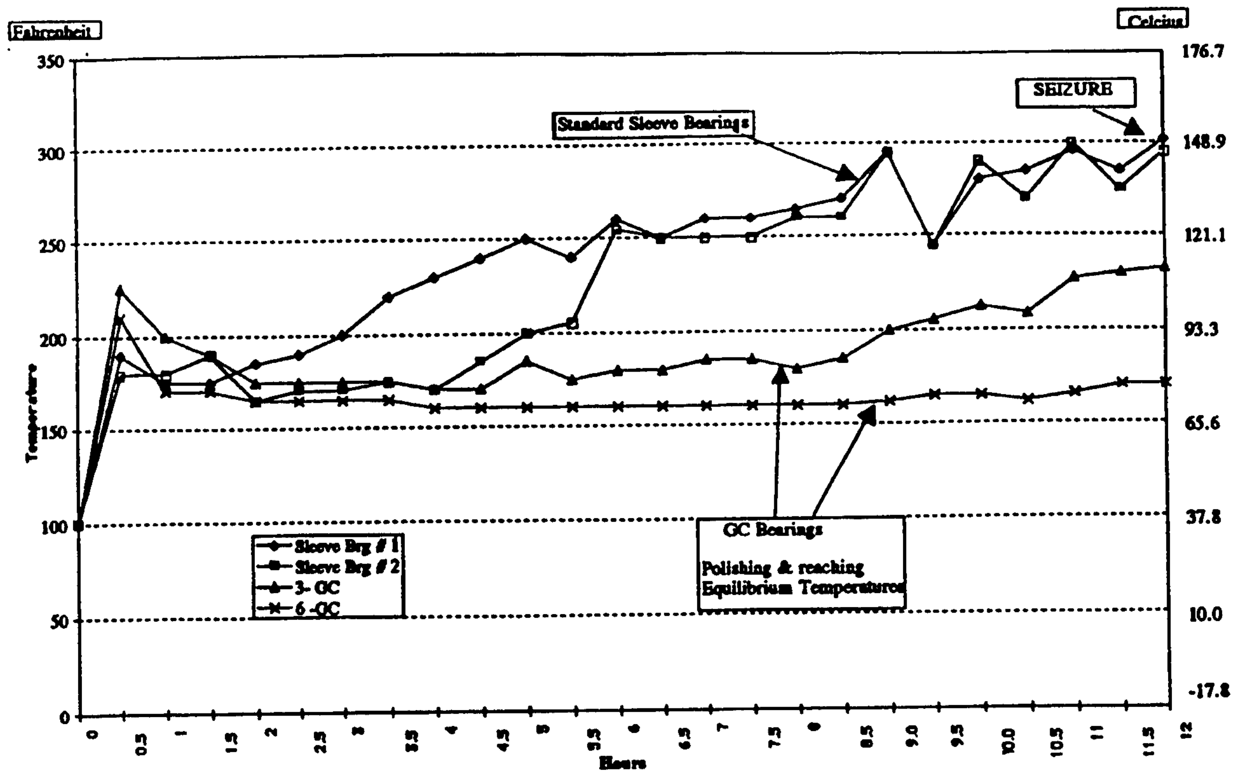

Figure 5. Feasibility Demonstration Geometrically Contoured Bearings - Comparison of GC & Standard Bearings

Both GC bearings reached an equilibrium at lower temperatures after peaking. This lower temperature equilibrium shows that the bearings had completed the polishing action which is a surface conformance between the mating, rubbing surfaces and the period of major wear (the initial break-in period) have been completed. This data has conclusively proved that GC PM Bearings are superior to standard PM sleeve and standard sliding bearings.

The Phase I SBIR funding did not permit an exhaustive comparison of a GC bearing to a roller or ball bearing, but did indicate quantitatively that the GC bearing was capable of sustaining loads considerably in excess of sliding bearings.

SBIR PHASE II: HMMWV QUALIFICATION TESTS

LABORATORY FOUR SQUARE TESTING

The objectives of this second phase were: first, to establish that a GC bearing capped universal joint could be used in the high torque HMMWV Front and Rear Propeller Shaft Drivelines and second, that it would reduce or eliminate the need for periodic maintenance lubrication.

The GC cup would also permit the use of a solid universal joint cross. A solid cross without the fatigue inducing lubrication channels and Zerk fittings would significantly improve the impact and fatigue resistance of universal joints and increase its overall operating life.

The "Four Square Test" is commonly utilized by the Automotive industry to qualify drivelines and their universal joints. The test equipment can be set up to simulate actual vehicle driveline operating angles and torque. Two propeller shafts (two driveshafts with their eight yokes and four universal joints) can be tested simultaneously.

The higher HMMWV torque required improved PM materials. Sinter Metals, Inc.-Chicago has assisted PMA in the development of PM materials and they manufactured the GC bearing cups. Five (5) proprietary formulations of powder mixes were developed and compared in bench tests and then comparatively evaluated on the Four Square equipment. Two materials were selected for the First HMMWV Field Tests (1995) to provide

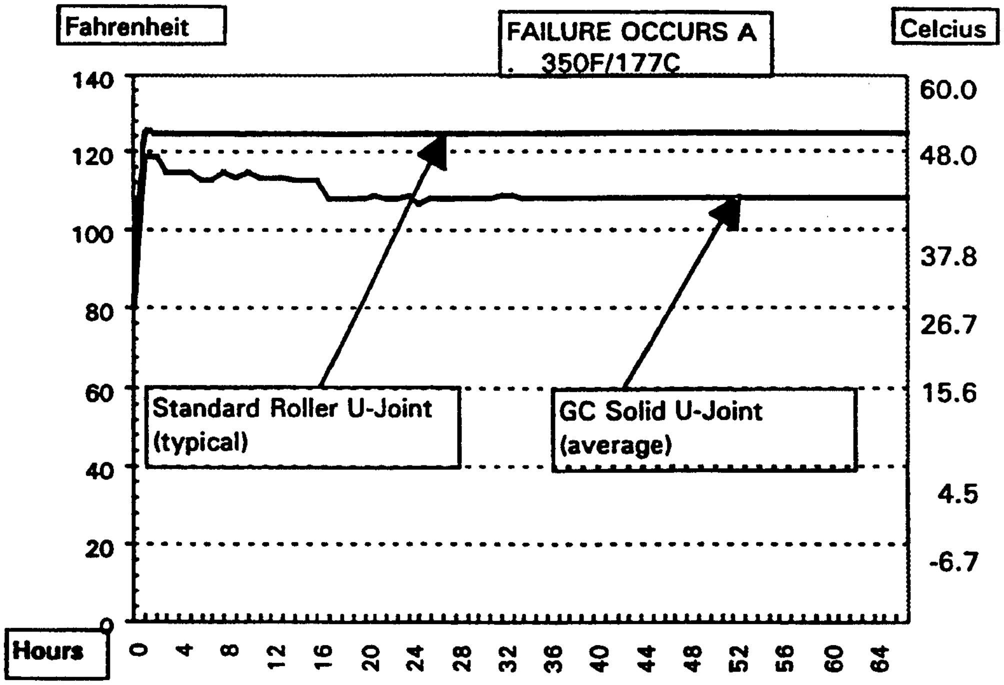

Figure 6. GC Bearing Life Test - Four Square

empirical information generated under field conditions.

As a result of the wear and impact analysis of the 1995 field tested universal joints, one material, referred to as MS, was selected.

The selected material (MS) was then subjected to various Four Square tests for verification. The Four Square equipment was also employed to verify contour design modifications.

Universal joint replacement is required every 19,308 km (12,000 miles) or one year of operation, whichever comes first. Field lubrication is presently required at 4,280 km (3,000 miles) or 3 months, whichever comes first.

The final Four Square tests were run to confirm that field lubrication is not required for GC capped universal joints. This confirming performance is illustrated in Figure 6.

Rolling bearing life data can be accelerated by Four Square equipment by increasing its operating variables. This cannot, however, be done to accelerate sliding bearing life. We were limited to run 67 hours or approximately 4265 km (2650 equivalent HMMWV miles) due to equipment availability.

The test parameters normally applied to standard needle roller universal joints for qualification are the angle, load and rpm; 4°, 579 N (1560 inch-pounds or 130 foot-pounds) and 3000 rpm respectively. The GC bearings were run at these loads and angles but were limited by the equipment to 1,750 rpm. As illustrated in Figure 6, the test equipment ran for 67 hours. The condition of the GC Solid Universal Joints indicated minimum wear and a capability to run beyond the specified HMMWV periodic lube change mileage.

Universal joint failure is defined to occur when their operating temperature reaches 177° C (350° F).

A typical standard universal joint with needle roller bearings runs at approximately 51.7° C (125° F), if wear debris is not created by impact or brinelling. Figure 6 assumes the standard roller universal joint does not encounter wear. Typically, however, wear begins to occur and the temperatures rise steadily.

As illustrated by the temperatures of Figure 6, the surface action of a GC Solid Universal Joint, in its first 15 to 20 hours of operation, removes the wear debris while polishing the surfaces. Continuing polishing reduces wear debris generation with a resultant dropping of temperature.

The GC temperature at start-up (boundary conditions) peaks and then begins dropping toward their equilibrium, unlike needle roller bearings whose temperatures generally rise quickly to their equilibrium. The GC bearings' temperature level after their initial polishing has been completed. At this point the debris has been effectively removed from between the surfaces and the universal joints are running at equilibrium temperatures indicating a long life.

HMMWV FIELD OPERATING PERFORMANCE

TEST RESULTS -- FIRST HMMWV FIELD TEST (1995)

The first field test involved selecting candidate HMMWV trucks from various U.S. Army National Guard Units and one U.S. Marine Corps Station and installing different GC & standard universal joint configurations (Table 1) on these vehicles. The GC Universal Joints used for this HMMWV field testing incorporated the permanent, no maintenance lubricant successfully tested in Phase I of this SBIR program.

Each unit was instructed to conduct their field exercises or typical routine activities as if the GC Universal Joints were not on the vehicle. They were also told to monitor the universal joints during periodic maintenance intervals or when necessary (i.e., report of failures). At the completion of the field exercise or a three (3) month period whichever is longer, they were instructed to remove all universal joints (both GC and standard) and send them back to PMA. PMA inspected and analyzed each universal joint.

Results of the first field tests indicated that all GC cups, on both the Front and Rear Propeller Shafts (Drivelines) met their requirements. No scoring was visible. They showed either no, or, minor wear. The Front Propeller Shaft cross trunnions on which the GC cups were mounted showed minor, acceptable, wear. The Rear Propeller Shaft mating universal joint cross trunnion surfaces, however, were scored. It was suspected that installation procedures were not closely followed. What was not known at this time is that the rear universal joints installed were of the incorrect size and that this scoring was probably not performance related.

Since the rear universal joints are normally more highly stressed than the front universal joints and the installation error was not yet identified, the twenty (20) pocket design was changed to six (6) pockets.

TEST RESULTS -- SECOND HMMWV FIELD TEST SERIES (1997)

The second field test involved selecting four (4) HMMWV trucks at the National Training Center at Ft. Irwin, CA and installing one (1) of four (4) different GC/Standard Universal Joint configurations (Table 2). These four (4) configurations are the ALL GC, MIX #1 (3-GC (Front)/2-STD (Rear)), MIX #2 (3-STD (Front)/ 2-GC (Rear)) and ALL STANDARD. Figure 7 shows the location of the five (5) test universal joints used on each HMMWV truck. A total of three (3) field tests were run using three (3) different test sample sets. Set #1 consisted of the six (6) pocket GC cups on standard universal joint crosses. Set #2 consisted of the six (6) pocket GC cups on the special solid universal joint crosses with no Zerk fittings. Set #3 consisted of the twelve (12) pocket GC cups on the special solid universal joint crosses with no Zerk fittings. All three (3) sets also had an equal number of standard universal joints to make up the four (4) test configurations. The removal and installation of these test sample sets were done by TARDEC engineers. Extra care was

Table 1. First HMMWV Field Test (1995) Configuration Chart

Vehicle	FN NEAPCO FRONT	MS NEAPCO FRONT	STD FRONT	FN DANA REAR	STD REAR	Test Activity National Guard
#1	2			2		Idaho
#2	2			2		Texas
#3	2				2	West Virginia
#4		2		2		Marine Corps
#5			2	2		Puerto Rico

taken to insure that each removal and installation was done properly and introduced no negative variables (i.e., improperly aligned universal joint) in the field testing.

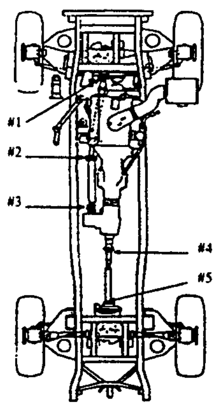

Figure 7. HMMWV Test Universal Joint Locations

MARCH FIELD TESTS

The scoring of the rear universal joints during the 1995 field tests indicated that they were not properly installed. Incorrect size universal joints for the rear propeller shaft were used in the 1995 field tests. The distances between the "ears" of the yokes on the Rear Propeller Shaft were greater than the Front Propeller Shaft yokes by 10.52 mm (0.414 inches). Though the GC cups fit the rear yokes and crosses properly, the universal joint cross itself was too small and floated between the "ears.", causing, or at least compounding, the trunnion scoring observed on the Rear Propeller Shaft Universal Joints in the First HMMWV Field Tests (1995).

The Rear Propeller Shaft Universal Joints are a different size than the Front Propeller Shaft Universal Joints. The HMMWV GC Solid Universal Joint cup design was based on the Front Propeller Shaft Universal Joints. The GC cup, however, is interchangeable with both Front and Rear Propeller Shaft Universal Joints.

In order to keep the field tests on schedule, the standard, needled, cups of the Rear Propeller Shaft Driveline Universal Joints were removed and replaced with GC cups. The Rear Propeller Shaft Universal Joints had GC cups mounted on standard, partially used crosses. GC Solid Universal Joints were installed in the Front Propeller Shaft Driveline.

Four (4) HMMWV trucks were used as test beds. The GC Universal Joints were intermixed with standard (needled) universal joints for direct one-on-one comparison of performance. The installation of the standard joint cups into their yokes caused swaging in some of the cups. Their alignment was difficult. The GC Universal Joints have a "lead-in" diameter on the cups for yoke insertion alignment. Their installation was simpler, without any swaging.

The analysis of the tested universal joints showed that there was no visible wear nor sign of heating on either the Front or Rear Propeller Shaft Universal Joints' GC cups. Their mating cross surfaces were polished by the oscillating driveline action.

All the standard cups had pronounced bluing indicative of overheating. Their mating cross trunnions had scoring from mild to heavy.

Table 2. Second HMMWV Field Test Configuration Chart

Vehicle	Propeller Shaft End Yoke FRONT (#1)	Propeller Shaft Slip Yoke FRONT (#2)	Propeller Shaft End Yoke FRONT (#3)	Propeller Shaft End Yoke REAR (#4)	Propeller Shaft End Yoke REAR (#5)
A	GC	GC	GC	GC	GC
B	GC	GC	GC	STD	STD
C	STD	STD	STD	GC	GC
D	STD	STD	STD	STD	STD

An unexpected action occurred on the standard universal joint cross trunnions of the four standard, partially used, rear universal joint crosses that were capped with GC cups. These crosses had mild scoring from previous use with standard (needled) cups. During the March field tests the Brinelling grooves and scoring were polished smooth by the GC cup surfaces.

APRIL & MAY FIELD TESTS

Four (4) HMMWV trucks were again used as test beds. The six (6) pocket, GC Universal Joints were again intermixed with standard (needled) universal joints for direct one-on-one comparison of performance. The GC Universal Joints with their "lead-in" diameter were easily installed. As in the March Tests, the standard, needled, cups required careful alignment. Some of these cups were again swaged.

In order to equip the HMMWV properly with the solid cross universal joints for both the Front and Rear Drivelines for the April & May field tests, a larger solid cross was required for the rear driveline. This larger solid cross was provided by NEAPCO, Inc. NEAPCO, one of PMA's subcontractors and the developer of the solid universal joint cross for this program, has begun marketing universal joints with solid crosses (without the GC bearing cups) commercially.

All (Front and Rear Propeller Shaft) solid universal joints with GC cups were polished with no visible wear nor signs of heating. All standard (needled) universal joints exhibited brinelling and scoring wear from mild to heavy and all their cups exhibited the bluing metal indicating excessive heating.

AUGUST & SEPTEMBER (FINAL) FIELD TESTS

The Final Field tests are still on-going. Only two configurations were run in August 1997. The remaining two configurations will run in September 1997.

The Final Field test duplicated the procedure of the preceding April & May test, i.e. four (4) HMMWV trucks with the same intermixed GC Solid and Standard Universal Joints assignments. The six (6) pocket GC cups were replaced by the twelve (12) pocket GC cups. This was based on the Four Square data demonstrating a lower operating temperature for the twelve (12) pocket, even though the six (6) pocket test results were acceptable.

As in the March and April & May field tests, all the GC cup capped universal joints were not scored and showed no signs of excessive heating and were easily assembled and removed. Their mating trunnions were polished.

As in the March and April & May field tests, all the standard (needled) universal joints' trunnions exhibited mild to heavy brinelling and light scoring wear. Some cups exhibited the bluing metal indicating excessive heating. Also, some of the cups were swaged during installation.

SUMMARY

It is concluded that the GC Solid Universal Joint has met HMMWV requirements , exceeds the performance of the standard, roller, universal joint and that it eliminates periodic maintenance.

It has been demonstrated that the GC Solid Universal Joint can replace the present lubrication channeled standard universal joints.

They are interchangeable with all present HMMWV universal joints and their commercial equivalents.

The "Lead-in" feature of GC cups permits simpler installation and insures more accurate alignment within the yokes.

The data from the HMMWV Four Square and Field tests demonstrate that no lubrication of the universal joint is required periodically.

Since the life test was limited to 4265 km (2650 miles), it was not established how far in excess of this distance the GC Solid Universal Joint could run without additional lubrication or when replacement of the universal joint would be required.

Limited funding for a complete, Four Square Sliding Life Test did not permit establishing whether the GC Solid Universal Joints need be replaced before the HMMWV is removed from active service every three years for a major

overhaul. The final HMMWV GC Solid Universal Joint design eliminates all bearing rollers in the bearing cups. Using the solid cross eliminates the need for the lubrication channels and Zerk fittings employed in the standard cross, thereby permitting a universal joint cross with a significant improvement in overall strength and fatigue resistance.

CONCLUSION

The key result of this U.S. Army SBIR development program is a new, innovative, low cost, bearing design procedure wherein wear is generally predictable and controllable.

The HMMWV program in addition to developing a field qualified universal joint simultaneously demonstrated the feasibility of the concept's applicability to bearing situations in general.

Driveline universal joints for heavy or medium Tactical Vehicles like the 5-ton truck appear logical extensions of the HMMWV development activity.

These HMMWV GC bearings are not limited to vehicular situations; they are also applicable to bearings in non-vehicular field equipment like generators, compressors, fans and pump motors.

It should be noted that this HMMWV program focused on a universal joint which is a high torque, moderate speed, oscillating application.

More light torque oscillating universal joints like Steering Universal Joints or Engine rocker arms appear obvious applications of this new GC design procedure.

Further, the GC concept is applicable to other roller bearings such as those used in rotating situations. Bearings operating as valve lifters and wheel bearings can be converted to GC bearings with their performance and cost benefits.

Another major class of GC bearing application is the lightly loaded, high speed, rotating ball bearing situations. Development work at PMA has successfully demonstrated GC Bearings running without balls in ball bearing applications.
Perhaps the most immediate benefit of the GC design procedure is the simple sliding bearing that served as the vehicle for demonstrating the GC concept's feasibility in the Phase I SBIR . The operating temperatures of the GC bearings were significantly lower than the standard sliding sleeve bearings. GC promises longer life and attendant cost reductions.

At this stage, however, GC bearings must be designed for each unique situation until a cataloged inventory is developed. No such inventory currently exists.

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NEW BEARING DESIGN CONCEPT

AN INNOVATIVE, U.S. ARMY, DESIGN CONCEPT FOR TACTICAL VEHICLE BEARINGS AND UNIVERSAL JOINTS

1997 SAE INTERNATIONAL TRUCK & BUS MEETING & EXPOSITION
NOVEMBER 17, 1997

Walter J. Maciag

Powdered Materials Applications, Inc.

Mark A. Mushenski

U.S. Army Tank-automotive & Armaments Command

AGENDA

INTRODUCTION

TECHNICAL BACKGROUND AND THEORY

FEASIBILITY DEMONSTRATION

HMMWV QUALIFICATION

- LABORATORY FOUR SQUARE
- TESTING HMMWV FIELD TESTS

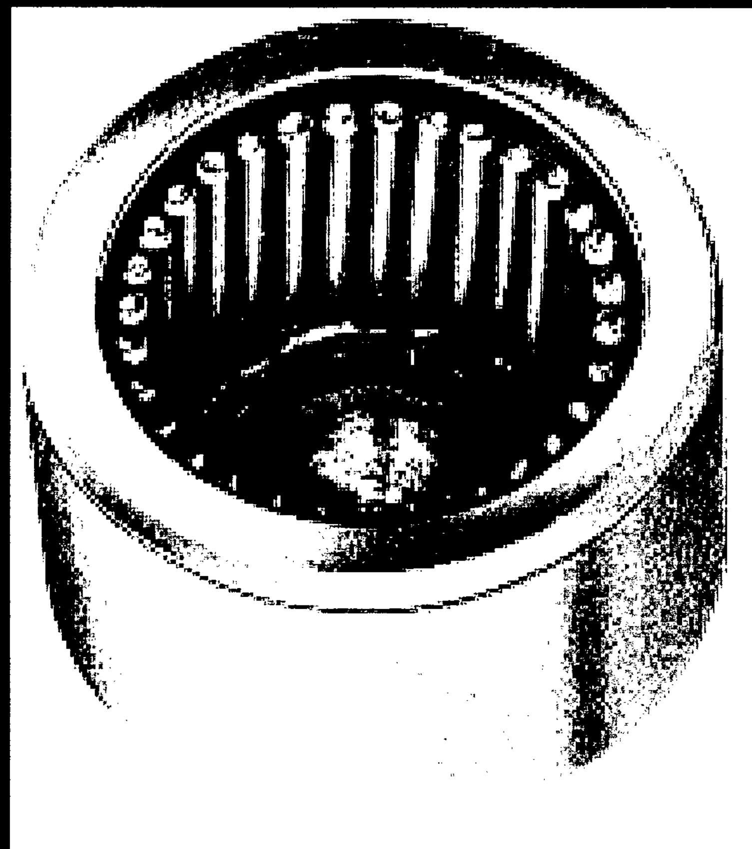
SUMMARY

CONCLUSION

INTRODUCTION

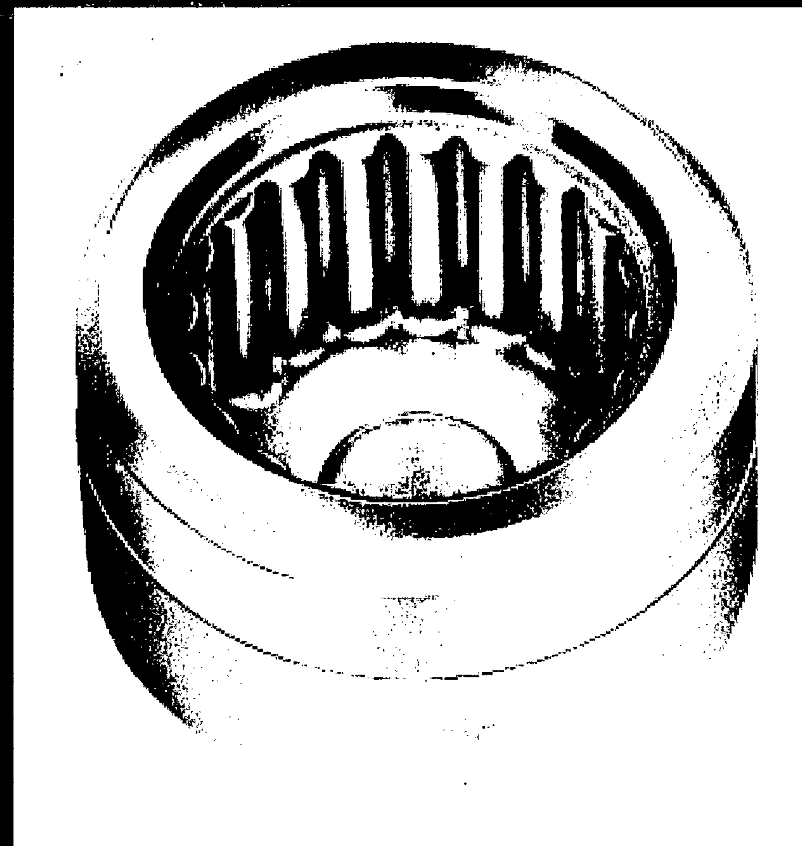
TECHNICAL BACKGROUND AND THEORY

STANDARD BEARING WITH ROLLERS



GC BEARING

- GEOMETRICALLY CONTOURED SURFACE
- NO ROLLERS
- POWDER MATERIALS (PM)
- REDUCE WEAR, OPERATING TEMPERATURE, AND OTHER DETRIMENTAL EFFECTS



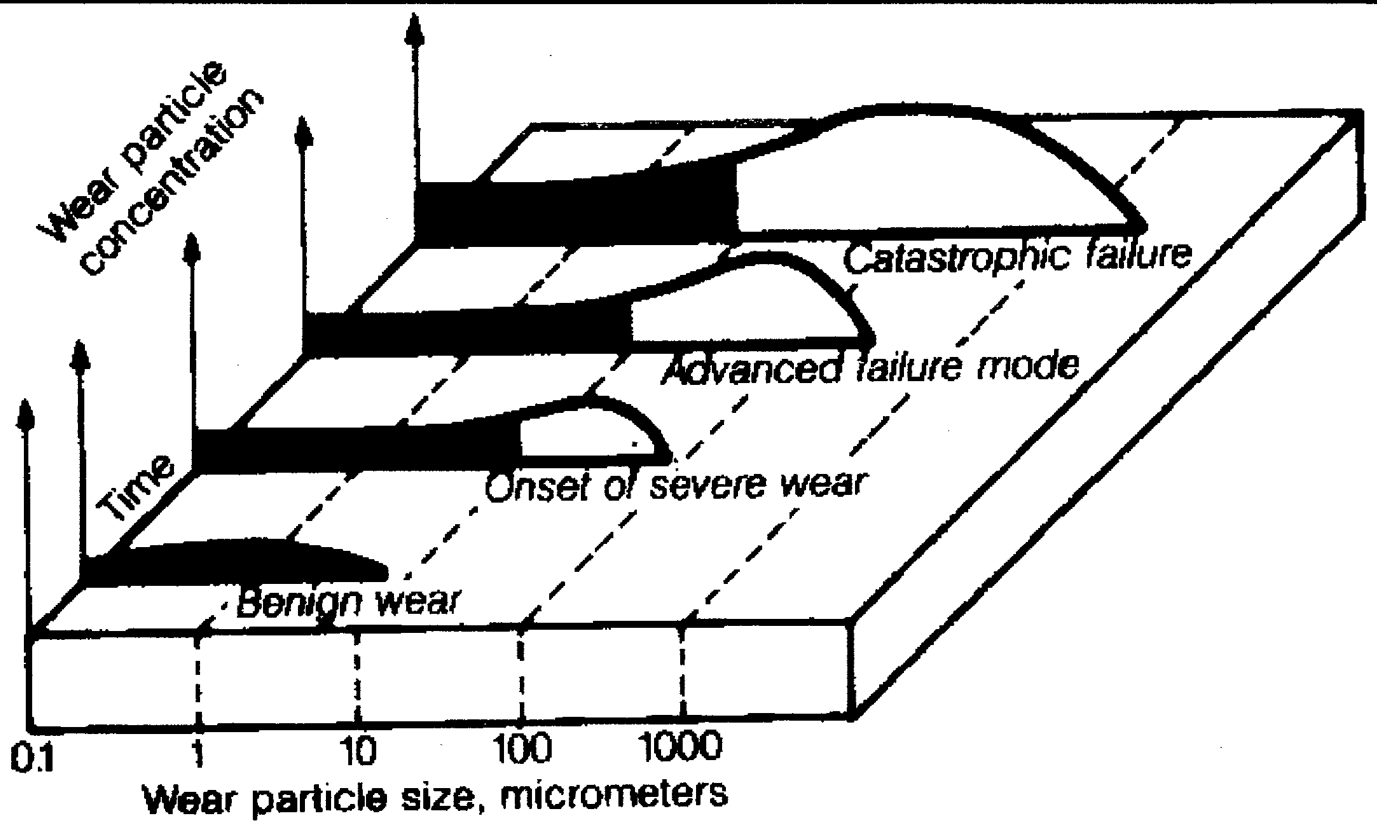
PM PROCESS

BLENDING: non-liquid, non-chemical, mixing

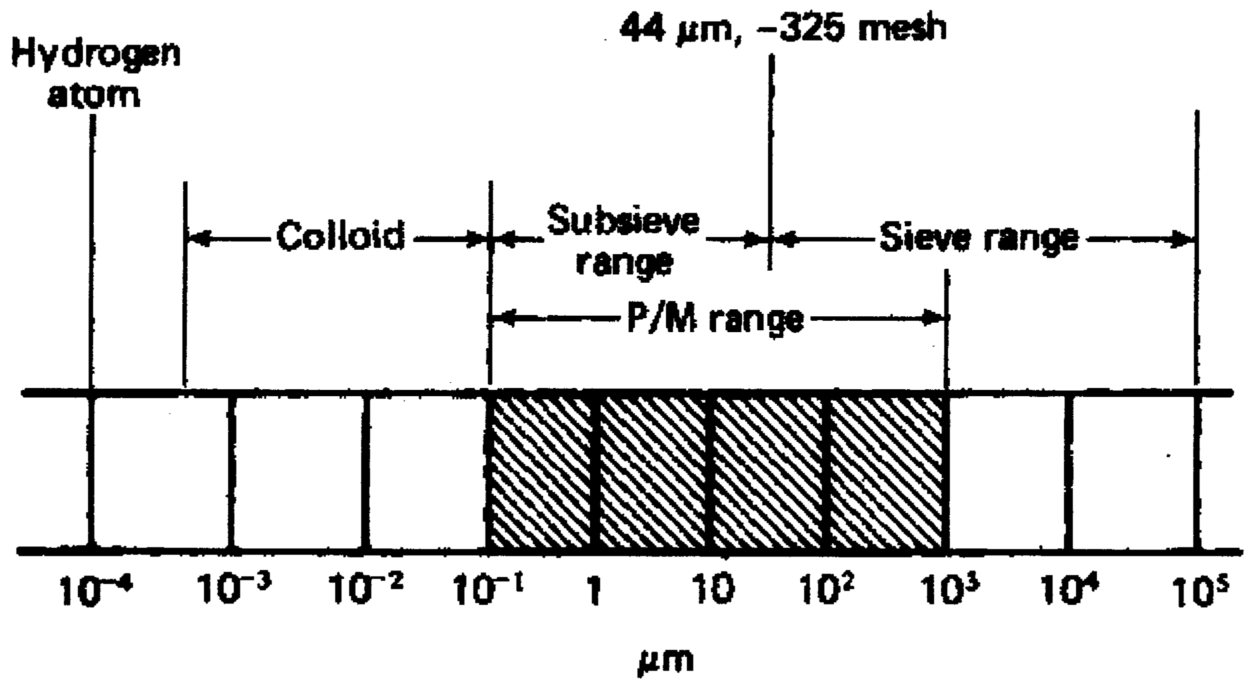
COMPACTION: pressed into the desired component's shape and dimensions

SINTERING: bonded in furnaces at controlled temperatures

WEAR PARTICLE SIZE CONCENTRATION



PARTICLE SIZE SPECTRUM



Particle size spectrum.

FEASIBILITY DEMONSTRATION

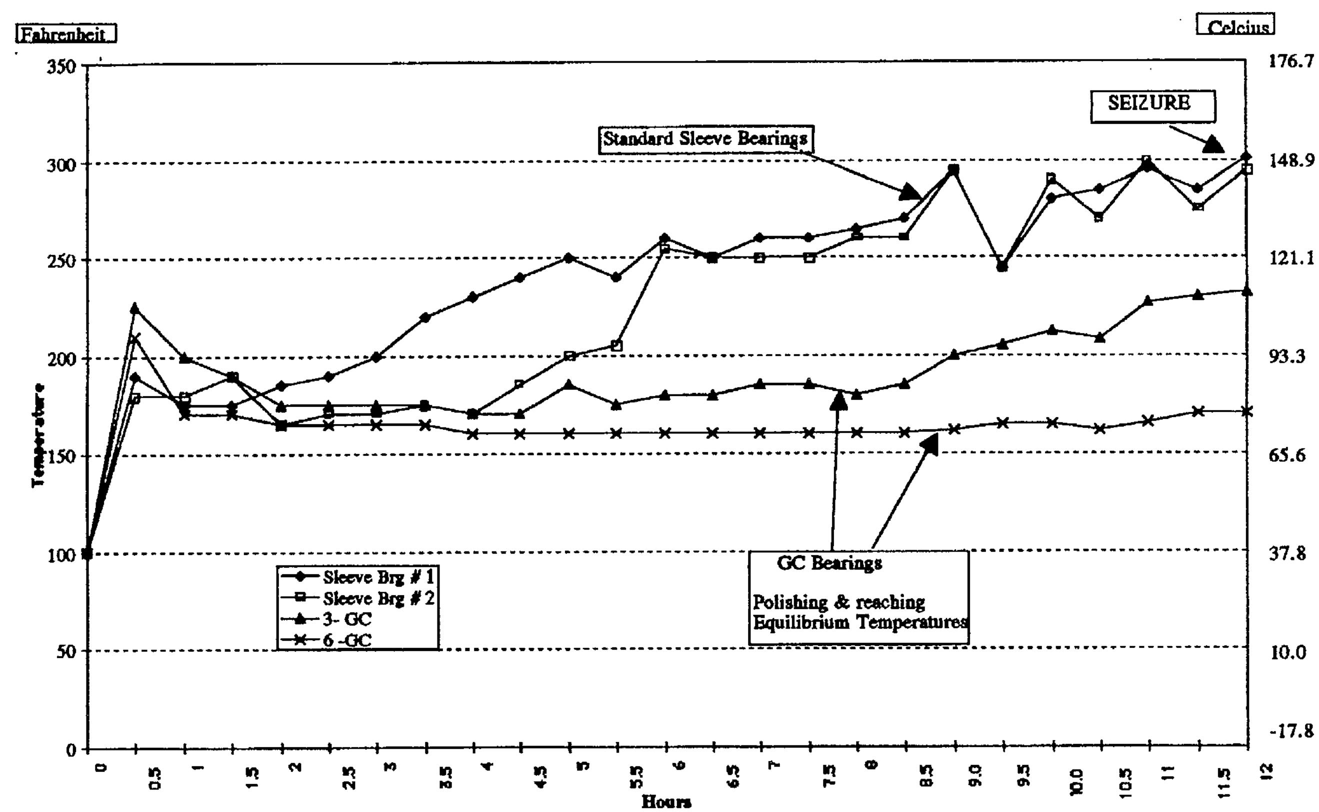
OBJECTIVE:

- TO DEMONSTRATE THE FEASIBILITY OF THE GC CONCEPT AND THE NEW BEARING DESIGN THEORY

BENCH TESTS:

- SAMPLES:
  - GC PM BEARINGS: 3-GC AND 6-GC
  - STANDARD PM SELF LUBE BEARINGS
- LOAD: 58 LBS
- SPEED: 1750 RPM
- AMBIENT TEMPERATURE: 100° F
- FAILURE:
  - AVERAGE BEARING TEMPERATURE IN EXCESS OF 350° F WHICH NORMALLY PRECEDES A BEARING SEIZURE

FEASIBILITY DEMONSTRATION GC BEARINGS COMPARISON OF GC VS STD BEARINGS



HMMWV QUALIFICATION

LABORATORY FOUR SQUARE TESTING

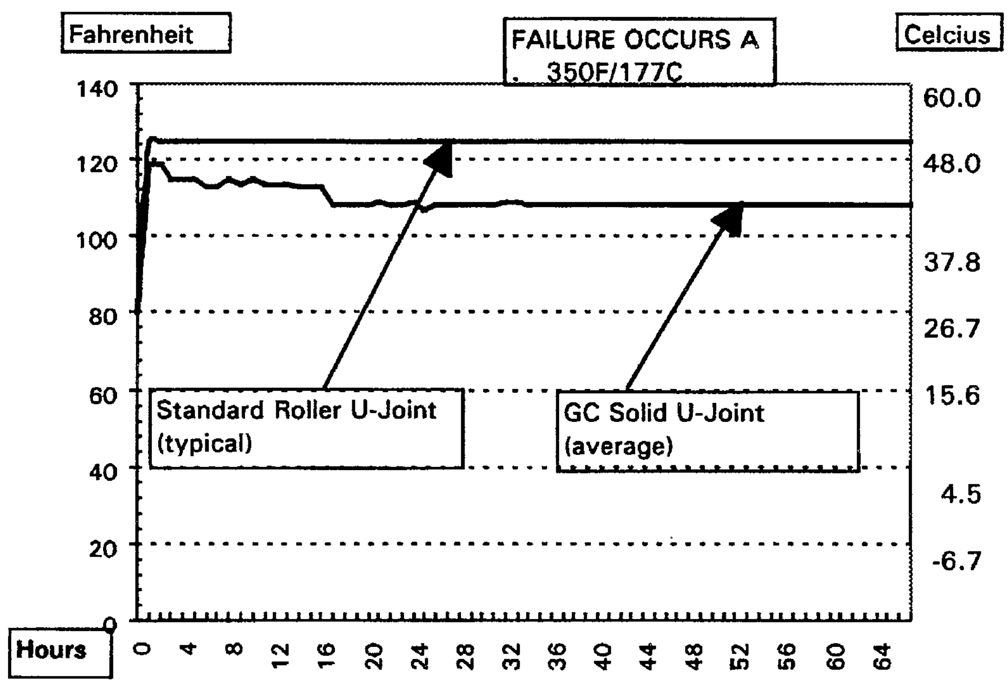
OBJECTIVE:

- TO ESTABLISH THAT A GC BEARING CAPPED UNIVERSAL JOINT COULD BE USED IN THE HIGH TORQUE HMMWV
- TO DEMONSTRATE THAT IT WOULD REDUCE OR ELIMINATE THE NEED FOR PERIODIC MAINTENANCE LUBRICATION

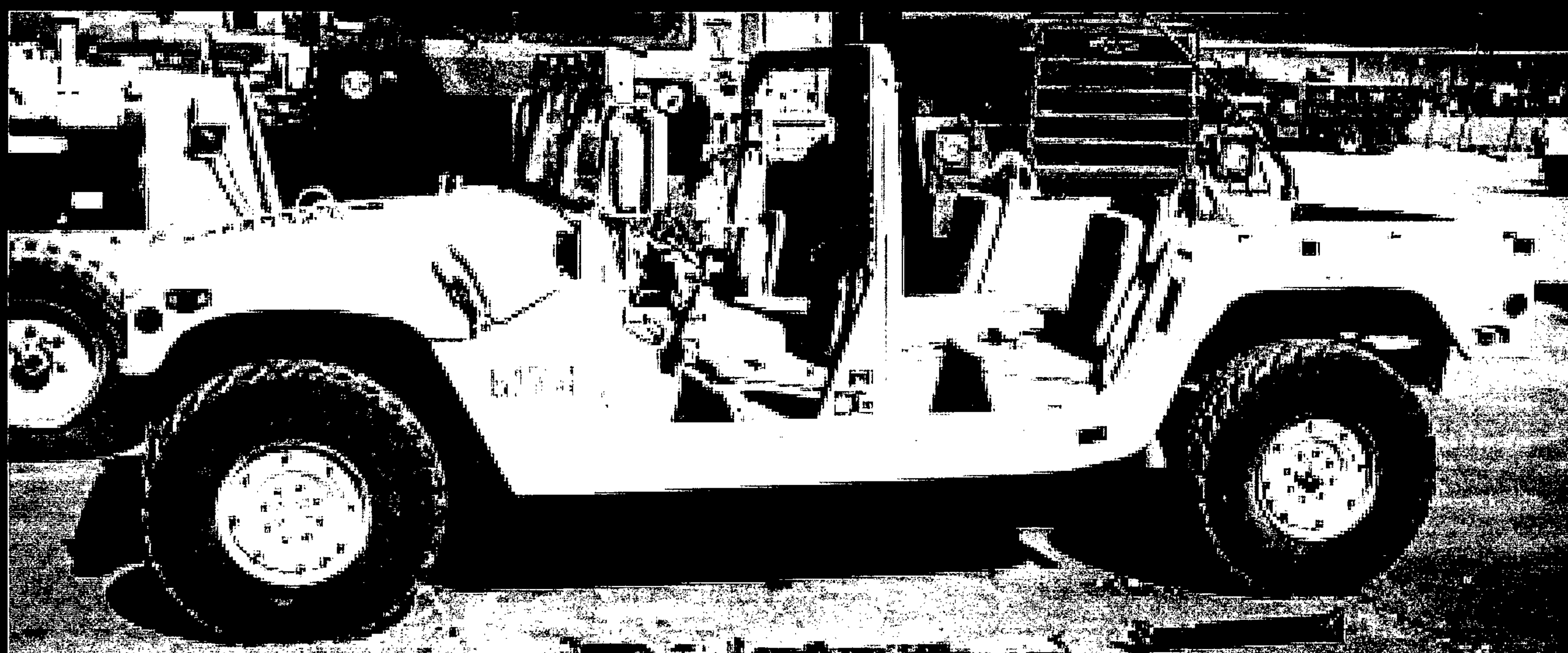
FOUR SQUARE TESTS:

- SAMPLES: FIVE (5) PROPRIETARY FORMULATIONS OF POWDER MIXES
- TEST PARAMETERS:
  - ANGLE: 4°
  - LOAD: 130 FT-LBS
  - SPEED: 1750 RPM (LIMIT)
- FAILURE:
  - AVERAGE BEARING TEMPERATURE IN EXCESS OF 350° F

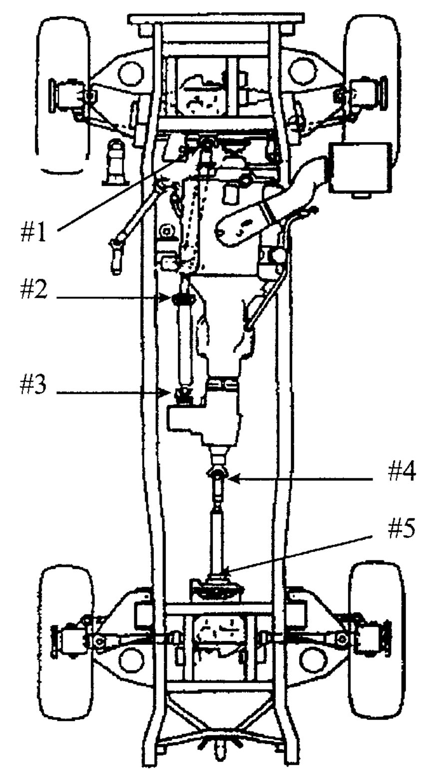
GC BEARING LIFE TEST - FOUR SQUARE



HMMMWV FIELD TESTS



HMMWV TEST UNIVERSAL JOINT LOCATIONS



FIRST HMMWV FIELD TEST (1995) CONFIGURATION CHART

Vehicle	FN NEAPCO FRONT	MS NEAPCO FRONT	STD FRONT	FN DANA REAR	STD REAR	Test Activity National Guard
#1	2			2		Idaho
#2	2			2		Texas
#3	2				2	West Virginia
#4		2		2		Marine Corps
#5			2	2		Puerto Rico

FIRST HMMWV FIELD TESTS (1995)

<u>RESULTS:</u>

ALL GC CUPS:

- NO SCORING
- NO, OR, MINOR WEAR

MATING FRONT PROPELLER SHAFT CROSS TRUNNIONS

- MINOR, ACCEPTABLE WEAR

MATING REAR PROPELLER SHAFT CROSS TRUNNIONS

- INSTALLATION PROCEDURES
- INCORRECT SIZE
- NOT PERFORMANCE RELATED

SECOND HMMWV FIELD TEST SERIES (1997)

TESTS:
- MARCH FIELD TESTS
- APRIL/MAY FIELD TESTS
- AUGUST/SEPTEMBER (FINAL) FIELD TEST

VEHICLES:
- FOUR (4) HMMWV TRUCKS

SITE:
- NATIONAL TRAINING CENTER (NTC), FT. IRWIN, CA

CONFIGURATIONS:

TEST SETS:
- SET #1: 6-GC WITH STANDARD CROSSES
- SET #2: 6-GC WITH SOLID CROSSES
- SET #3: 12-GC WITH SOLID CROSSES

SECOND HMMWV FIELD TEST CONFIGURATION CHART

Vehicle	Test Configuration	Propeller Shaft End Yoke FRONT (#1)	Propeller Shaft Slip Yokes FRONT (#2)	Propeller Shaft End Yoke FRONT (#3)	Propeller Shaft End Yoke REAR (#4)	Propeller Shaft End Yoke REAR (#5)
A	GC	GC	GC	GC	GC	GC
B	Mix #1	GC	GC	GC	STD	STD
C	Mix #2	STD	STD	STD	GC	GC
D	Standard	STD	STD	STD	STD	STD

MARCH FIELD TEST

SET #1	GC BEARING	STD BEARING
CUPS	NO VISIBLE WEAR NO SIGNS OF HEATING	BLUING METAL (OVERHEATING)
TRUNNION (CROSS)	POLISHED	SCORING (MILD TO HEAVY)

APRIL/MAY FIELD TESTS

SET #2	GC BEARING	STD BEARING
CUPS	NO VISIBLE WEAR NO SIGNS OF HEATING	BLUING METAL (EXCESSIVE HEATING)
TRUNNION (CROSS)	POLISHED	BRINELLING AND SCORING WEAR (MILD TO HEAVY)

AUGUST/SEPTEMBER FIELD TESTS

SET #3	GC BEARING	STD BEARING
CUPS	NO VISIBLE WEAR NO SIGNS OF HEATING EASILY ASSEMBLED & REMOVED	BLUING METAL (EXCESSIVE HEATING) SWAGED DURING INSTALLATION
TRUNNION (CROSS)	POLISHED	BRINELLING (MILD TO HEAVY) SCORING (LIGHT)

HMMWV FIELD TEST MILEAGE CHART

Vehicle	Test Configuration	HMMWV Bumper Number	PMA Test Set #1	PMA Test Set #2	PMA Test Set #3	TOTAL MILEAGE
A	GC	8174	1043	4	X	1047
A	GC	8595	X	X	144	144
B	Mix #1	8228	443	1903	1221	3567
C	Mix #2	8272	845	1439	X	2284
C	Mix #2	8965	X	X	351	351
D	Standard	8065	913	2036	1067	4016
					TOTAL	11,409

SUMMARY COMPARISONS MAINTENANCE

	STANDARD (ROLLER) UNIVERSAL JOINT	GC SOLID UNIVERSAL JOINT
LUBRICATION FREQUENCY (Project Objective)	3000 miles/ 3 months	NONE
REPLACEMENT FREQUENCY	12,000 miles/ 12 months	NOT DETERMINED
INSTALLATION		SIMPLER (LEAD-IN)

SUMMARY COMPARISONS PERFORMANCE

	STANDARD (ROLLER) UNIVERSAL JOINT	GC SOLID UNIVERSAL JOINT
FATIGUE RESISTANCE		GREATER
WEAR - CROSS TRUNNION		LESS
WEAR - CUP CASE		LESS
WEAR - CUP EXTERIOR (SWAGE)		NONE
NORMAL OPERATING TEMPERATURE	51.7°C / 125°F	40.6°C / 105°F

SUMMARY

MEETS HMMWV REQUIREMENTS

EXCEEDS STANDARD, ROLLER, UNIVERSAL JOINT PERFORMANCE

ELIMINATES PERIODIC MAINTENANCE

- NO LUBRICATION
- INTERCHANGEABLE

SIMPLIFIES INSTALLATION

- ELIMINATES ALL NEEDLE BEARINGS
- “LEAD-IN” CUP FEATURE

REPLACES LUBRICATION CHANNELED STANDARD U-JOINT

- ELIMINATES LUBRICATION CHANNELS AND ZERK FITTINGS
- SIGNIFICANT IMPROVEMENT IN OVERALL STRENGTH & FATIGUE RESISTANCE

CONCLUSIONS

A NEW, INNOVATIVE, LOW COST, BEARING DESIGN

LOWER OPERATING TEMPERATURES

LONGER LIFE

COST SAVINGS

OTHER BEARING APPLICATIONS

- VEHICULAR
- NON-VEHICULAR

APPLICATIONS

HIGH TORQUE, MODERATE SPEED, OSCILLATING
- HMMWV UNIVERSAL JOINT

LIGHT TORQUE, OSCILLATING
- STEERING UNIVERSAL JOINTS
- ENGINE ROCKER ARMS

ROTATING (OTHER ROLLER BEARINGS)
- VALVE LIFTERS
- WHEEL BEARINGS

LIGHTLY LOADED, HIGH SPEED, ROTATING (BALL BEARINGS)

SLIDING BEARINGS